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Herbaceous Understory Phenology, Growth, Reproduction, and Germination Response to Forest Restoration Treatments

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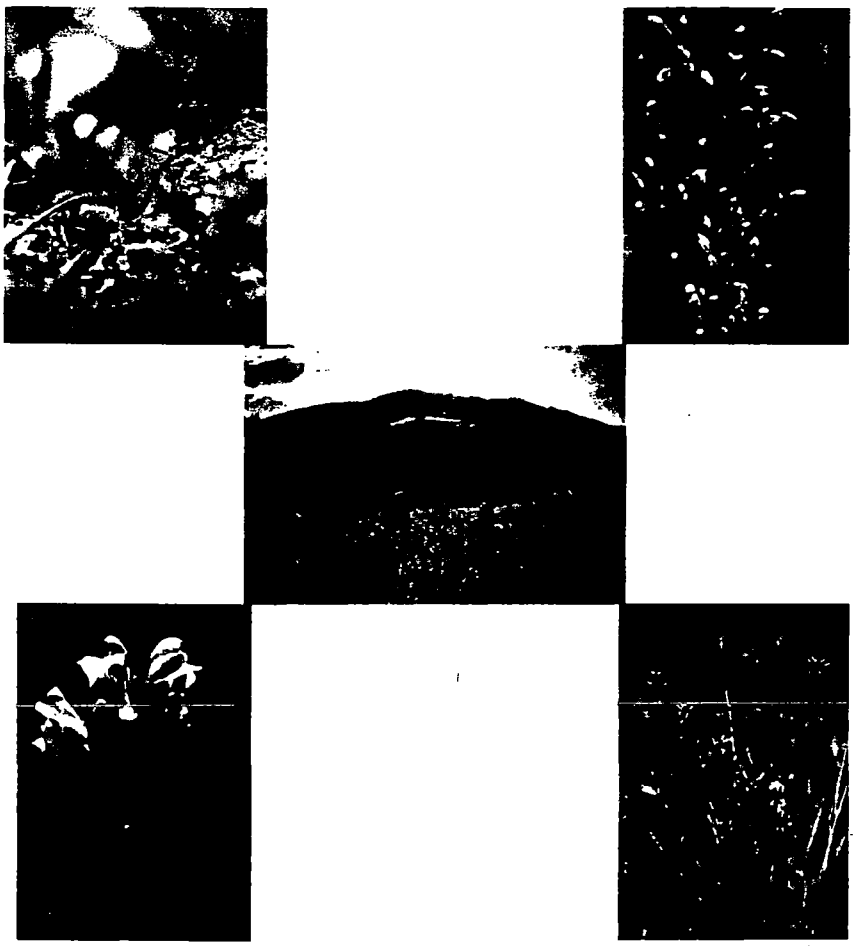

Research Joint Venture Agreement
No. RMRS-99159-RJVA

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Margaret M. Moore
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FINAL REPORT

HERBACEOUS UNDERSTORY PHENOLOGY, GROWTH, REPRODUCTION, AND GERMINATION RESPONSE TO FOREST RESTORATION TREATMENTS

Research Joint Venture Agreement
No. RMRS-99159-RJVA

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PREFACE

This project was part of a Research Joint Venture between Rocky Mountain Research Station and Northern Arizona University; and part of the Flagstaff Urban-Wildland Interface project. The portion of this study conducted on growth and reproduction of the two native species, *Lupinus argenteus* and *Blepharoneuron tricholepis*, was the focus of a master's thesis that will be defended in spring 2003 : Lisa M. Machina.

PRESENTATIONS AND PUBLICATIONS

The following is list of presentations, posters, and publications produced fro this project.

PRESENTATIONS

Machina, Lisa M., September 2002. Native plant response to ecological restoratior treatments in ponderosa pine forests. Guest lecture and plant walk at Gus Pearsor Natural Area Restoration Treatments for the Arizona Native Plant Society, Flagsta AZ.

Machina, Lisa M., Margaret M. Moore, and Laura E. DeWald, August 2002. *Lupinu argenteus* and *Blepharoneuron tricholepis* growth and reproductive potential in ponderosa pine restoration treatments. Annual Joint Meeting of the Ecological Society of America (ESA) and the Society for Ecological Restoration (SER) Conference oral presentation in Tucson, AZ.

Machina, L.M. and J.P. Roccaforte. May 2002. Introduction to ecological restoratio Guest lecture (at NAU's Lonetree Restoration site) discussing ecological restoratio for Haddie Braun's biology class, Coconino Community College, Flagstaff, AZ.

Machina, Lisa M., May 2001. Field presentation of *Lupinus argenteus* and *Blepharoneuron tricholepis* phenology and reproduction data collection at Gus Pearson Natural Area. ERI training week oral presentation at GPNA.

Machina, Lisa M., Margaret M. Moore, and Laura E. DeWald, April 2001. Reproductive and phenological characteristics of *Lupinus argenteus* and *Blepharoneuron tricholepis* in ponderosa pine restoration treatments. Restoring th

Rockies: Central Rockies Chapter of Society for Ecological Restoration (CeRSER) conference oral presentation in Keystone, CO.

Machina, Lisa M., Margaret M. Moore, and Laura E. DeWald, March 2001. Reproductive and phenological characteristics of *Lupinus argenteus* and *Blepharoneuron tricholepis* in ponderosa pine restoration treatments. ERI weekly meeting PowerPoint presentation.

Machina, Lisa M., September 2002. Field plant walk for Arizona Native Plant Society at Saddle Mountain, Coconino National Forest.

Machina, Lisa M., Margaret M. Moore, and Laura E. DeWald, November 2000. Growth and reproductive potential of *Lupinus argenteus* and *Blepharoneuron tricholepis* in ponderosa pine restoration treatments. ERI weekly meeting PowerPoint presentation.

Machina, Lisa M., August 1999. Field presentation for elementary students in Summer Science Camp on ponderosa pine restoration and native plant response at Gus Pearson Natural Area.

Machina, Lisa M., July 1999. Field presentation for visiting group of Russian scientists on ponderosa pine restoration and native plant response at Gus Pearson Natural Area.

POSTERS

Machina, Lisa M., Margaret M. Moore, and Laura E. DeWald, April 2001. Reproductive and phenological characteristics of silvery lupine and pine dropseed in ponderosa pine restoration treatments. Putting the Pieces Together: ERI-sponsored ecological restoration conference poster presentation in Flagstaff, AZ.

Machina, Lisa M. April 2001. Native Plants in a Southwestern Ponderosa Pine Ecosystem. Poster for ERI-sponsored Earth Day booth in Flagstaff, AZ.

Machina, Lisa M. April 2000. Native Plants in a Southwestern Ponderosa Pine Ecosystem. Poster for ERI-sponsored Earth Day booth in Flagstaff, AZ.

M. S. THESIS

Machina, Lisa M., 2003. *Lupinus argenteus* and *Blepharoneuron tricholepis* growth and reproduction responses to ponderosa pine restoration. M.S Thesis, Northern Arizona University, Flagstaff, AZ.

TABLE OF CONTENTS

Preface ii
Presentations and Publications ii
Table of Contents iv
List of Tables v
List of Figures vi
Executive Summary viii
Chapter 1: Introduction 1
  Plant Biology 2
  Research Hypotheses 5
  Objectives 6
Chapter 2: Methods 7
  Study Sites 7
  Sampling 9
  Statistical Analyses 11
Chapter 3: Results and Discussion of Objective 1: Increases in plant phenology, growth, and reproduction associated with ponderosa pine forest restoration in northern Arizona 13
  Phenology 13
  Growth and Reproduction 16
  Environmental Variables 34
  Relationships 42
Chapter 4: Results and Discussion of Objectives 2 and 3: Seed collection and seed germination of two native plants and two non-native noxious weeds in northern Arizona ponderosa pine forests 49
  Seed Collection and Storage 49
  Seed Germination 51
Chapter 5: Management Implications 53
  Noxious Weeds 54
  Management Implications and Future Research Recommendations 54
  Conclusion 55
Chapter 6: Literature Cited 56

LIST OF TABLES

Table 1. Phenophases observed in *Lupinus argenteus*, *Blepharoneuron tricholepis*, and *Linaria dalmatica* 14

Table 2. *Lupinus argenteus* ANOVA summary comparing variables in the control, partial and full treatments at GPNA in 1999, 2000, and 2001 17

Table 3. *Blepharoneuron tricholepis* ANOVA summary comparing variables in the control, partial and full treatments at GPNA in 1999, 2000, and 2001 18

Table 4. *Linaria dalmatica* ANOVA summary comparing variables in the control and thin plus burn treatment at FUWI in 2001 19

Table 5. *Lupinus argenteus* ANOVA summary comparing daily PAR and forest floor depths in the control, partial and full treatments at GPNA in 2001 35

Table 6. *Blepharoneuron tricholepis* ANOVA summary comparing daily PAR and forest floor depths in the control, partial and full treatments at GPNA in 2001 37

Table 7. Seed germination results performed by the Arizona State Seed Testing Lab on seeds collected in 1999 from the Coconino National Forest 41

Table 8. Light intensity and forest floor depth simple linear regressions against *L. argenteus* growth and reproduction 44

Table 9. Light intensity and forest floor depth simple linear regressions against *L. argenteus* growth and reproduction under different tree canopy cover types 44

Table 10. Light intensity and forest floor depth simple linear regressions against *Blepharoneuron tricholepis* growth and reproduction 46

Table 11. Light intensity and forest floor depth simple linear regressions against *B. tricholepis* growth and reproduction under different tree canopy cover types 46

Table 12. Light intensity and forest floor depth simple linear regressions against *Linaria dalmatica* growth and reproduction 48

Table 13. Light intensity and forest floor depth simple linear regressions against *L. dalmatica* growth and reproduction under different tree canopy cover types 48

Table 14. Seed germination results performed by the Arizona State Seed Testing Lab on seeds collected in 1999 from the Coconino National Forest 53

LIST OF FIGURES

Figure 1. Topographic map of the Flagstaff area and Fort Valley Experimental Forest surrounded by the Coconino National Forest 7
Figure 2. Aerial view of a stem map of the GPNA restoration treatments. Stem map was constructed after thinning treatments were implemented in 1993 (Covington et al. 1997) 8
Figure 3. Topographic map of the FUWI study site including EB1, EB2, and EB3. EB3-1 an EB3-2 are the specific sites where *Linaria dalmatica* research was conducted 8
Figure 4. Average phenophases per data collection date of *Lupinus argenteus* at the GPN study site in 2001 15
Figure 5. Average phenophases per data collection date of *Blepharoneuron tricholepis* at th GPNA study site in 2001 16
Figure 6. Average phenophases per data collection date of *Linaria dalmatica* at the GPNA study site in 2001 16
Figure 7. *Lupinus argenteus* maximum height per indicator plant in 1999, 2000, and 2001 i control, thin only partial, and thin plus burn full treatments at GPNA 20
Figure 8. *Blepharoneuron tricholepis* maximum height per indicator plant in 1999, 2000, an 2001 in control, thin only partial, and thin plus burn full treatments at GPNA 20
Figure 9. ANOVA for *Linaria dalmatica* maximum height per indicator plant in 2001 in contr and thin + burn treatments at FUWI 21
Figure 10. *Lupinus argenteus* peak cover per indicator plant in 1999, 2000, and 2001 in control, thin only partial, and thin plus burn full treatments at GPNA 22
Figure 11. ANOVA for *Lupinus argenteus* peak basal cover per indicator plant in 1999 in control, thin only partial, and thin plus burn full treatments at GPNA 22
Figure 12. *Blepharoneuron tricholepis* peak basal cover per indicator plant in 1999, 2000, and 2001 in control, thin only partial, and thin plus burn full treatments at GPNA 23
Figure 13. ANOVA for *Linaria dalmatica* peak aerial cover per indicator plant in 2001 in control and thin + burn treatments at FUWI 23
Figure 14. ANOVA for *Linaria dalmatica* peak basal cover per indicator plant in 2001 in control and thin + burn treatments at FUWI 24
Figure 15. ANOVA for *Linaria dalmatica* number of stems per indicator plant in 2001 in control and thin + burn treatments at FUWI 25
Figure 16. *Lupinus argenteus* peak number of reproductive stalks per indicator plant in 199 2000, and 2001 in control, thin only partial, and thin plus burn full treatments at GPNA..26
Figure 17. ANOVA for *Lupinus argenteus* peak number of reproductive stalks per indicator plant in 2000 in control, thin only partial, and thin plus burn full treatments at GPNA 26
Figure 18. *Blepharoneuron tricholepis* peak number of reproductive stalks per indicator pla in 1999, 2000, and 2001 in control, thin only partial, and thin plus burn full treatments at GPNA 27
Figure 19. ANOVA for *Linaria dalmatica* peak number of reproductive stalks per indicator plant in 2001 in control and thin + burn treatments at FUWI 27
Figure 20. Average number of reproductive stalks per indicator plant at each data collectio date of *Lupinus argenteus* at the GPNA study site in 2001 29
Figure 21. Average number of reproductive stalks per indicator plant at each data collectio date of *Blepharoneuron tricholepis* at the GPNA study site in 2001 29

Figure 22. Average number of reproductive stalks per indicator plant at each data collection date of *Blepharoneuron tricholepis* at the GPNA study site in 2001 30
Figure 23. *Lupinus argenteus* peak density per $1m^2$ plot in 1999, 2000, and 2001 in control, thin only partial, and thin plus burn full treatments at GPNA 31
Figure 24. *Blepharoneuron tricholepis* peak density per $1m^2$ plot in 1999, 2000, and 2001 in control, thin only partial, and thin plus burn full treatments at GPNA 32
Figure 25. ANOVA for *Linaria dalmatica* peak density per $1m^2$ plot in 2001 in control and thin + burn treatments at FUWI 32
Figure 26. ANOVA for *Lupinus argenteus* peak biomass per indicator plant in 2001 in control, thin only partial, and thin plus burn full treatments at GPNA 33
Figure 27. ANOVA for *Blepharoneuron tricholepis* peak biomass per indicator plant in 2001 in control, thin only partial, and thin plus burn full treatments at GPNA 34
Figure 28. ANOVA for *Linaria dalmatica* peak biomass per indicator plant in 2001 in control and thin + burn treatments at FUWI 34
Figure 29. ANOVA comparison between treatments of light intensity (PAR) on *Lupinus argenteus* plots at morning, midday, and afternoon 35
Figure 30. Average daily light intensity (PAR) comparison between treatments on *Lupinus argenteus* plots using ANOVA 36
Figure 31. Comparison of litter accumulation and fermentation + humus accumulation between treatments on *Lupinus argenteus* plots using ANOVA 36
Figure 32. ANOVA comparison between treatments of light intensity (PAR) on *Blepharoneuron tricholepis* plots at morning, midday, and afternoon 38
Figure 33. Average daily light intensity (PAR) comparison between treatments on *Blepharoneuron tricholepis* plots using ANOVA 38
Figure 34. Comparison of litter accumulation and fermentation + humus accumulation between treatments on *Blepharoneuron tricholepis* plots using ANOVA 39
Figure 35. a) Monthly 2001 precipitation, in one location at study site, b) weekly mean volumetric water content (VWC) of soil, and c) maximum weekly volumetric water content of soil 40
Figure 36. Average daily light intensity (PAR at 8-10am and 11am-1pm) comparison between treatments on *Linaria dalmatica* plots using ANOVA 42
Figure 37. Comparison of litter accumulation and fermentation + humus accumulation between treatments on *Linaria dalmatica* plots using ANOVA 42

EXECUTIVE SUMMARY

Ponderosa pine forest ecosystems throughout the Southwest have become unnaturally dense and generally degraded since the introduction of land use practices such as livestock overgrazing, harvesting of old-growth trees, and fire suppression associated with Euro-American settlement in the late nineteenth centur In the absence of naturally-occurring low intensity surface fires over the past centur ponderosa pine forests are in danger of catastrophic, stand-replacing fires. Work is underway to reverse these changes and restore forests to more nearly natural conditions. Detailed information regarding responses of specific plant species to restoration treatments is needed.

In this study, we examined phenology, growth, and reproduction of the native legume *Lupinus argenteus* Pursh (silvery lupine), the endemic bunchgrass *Blepharoneuron tricholepis* (Torr.) Nash (pine dropseed), and the noxious weed *Linaria dalmatica* (L.) P. Mill. (Dalmatian toadflax) in thin only (natives only) and thin plus burn restoration treatments in northern Arizona ponderosa pine forests. *L. argenteus* and *B. tricholepis* were studied at the Gus Pearson Natural Area from 1999 to 2001. *L. dalmatica* was studied at the Flagstaff Urban-Wildland Interface in 2001. Seed collection, processing, and germination response of the three target species plus the noxious weed, *Bromus tectorum* L. (cheatgrass) were also examined. Responses to restoration treatments of thinning and/or thinning plus burning were generally positive for *L. argenteus*, *B. tricholepis*, and *L. dalmatica*. Results include the following key findings:

1. Phenology information was collected every other week throughout the 2001 growing season, and repeated measures analyses showed that all three species displayed significant date by treatment phenophase interactions (*L. argenteus*, $p < 0.0001$, *B. tricholepis*, $p < 0.0001$, *L. dalmatica*, $p = 0.02169$).
2. For all three species, lowest average phenophases during reproductive periods occurred in the control treatment, due, in part, to a lower percentage of control plants reaching reproductive maturity.
3. We studied year by treatment interactions of growth and reproduction variables for *L. argenteus* and *B. tricholepis*. Growth and reproduction of *L. argenteus* wer most affected by the 2000 drought year, and in effect, were most affected by yearly variations. For *L. argenteus*, there were significant year by treatment interactions for number of reproductive stalks ($p = 0.0108$) and density ($p < 0.0001$), but not for height or cover. For *B. tricholepis*, growth was more stable between years, however, number of reproductive stalks had a significant year by treatment interaction ($p = 0.0602$).
4. *L. argenteus* plant height was not different between treatments in 1999, 2000, or 2001. In each of the three years, *L. argenteus* cover, number of reproductive stalks, and density were generally greater in the thin only and thin plus burn treatments compared with the control. However, significant differences in *L. argenteus* cover and number of reproductive stalks were generally detected between the control and thin only treatments, whereas significant differences in density were detected between the control and thin plus burn treatment. *L.*

argenteus biomass, measured in 2001 only, was greater in both restored treatments, but was significantly greater in the thin only treatment compared with the control ($p = 0.0496$).

5. *B. tricholepis* plant height, basal cover, number of reproductive stalks, and density were generally greater in the thin only and thin plus burn treatments compared with the control in 1999, 2000, or 2001. The thin plus burn treatment especially favored *B. tricholepis* plants. In each of the three years, *B. tricholepis* height, cover, and reproduction were generally significantly greater in the thin only and thin plus burn treatments than the control. Significant differences between treatments in *B. tricholepis* density were not detected in any of the three years. *B. tricholepis* biomass, measured in 2001 only, was significantly greater in the thin only and thin plus burn treatments compared with the control ($p = 0.0496$).
6. All *L. dalmatica* growth and reproduction variables measured in 2001 were greater in the thin plus burn treatment than the control, but only differences in aerial cover and density were statistically significant (cover $p = 0.0037$, density $p < 0.0001$).
7. We also compared *L. dalmatica* growth and reproduction between canopy cover types and treatments and found that found that in the control treatment, aerial cover was significantly greater in the postsettlement retained canopy cover type than the grass cover type ($p = 0.0236$), showing the competitive ability of native grasses in the control treatment.
8. We additionally compared *L. dalmatica* growth and reproduction between canopy cover types when data from both treatments were lumped, and found that *L. dalmatica* aerial and basal cover were significantly greater in the postsettlement removed canopy type than both the presettlement canopy and grass cover types (aerial cover $p = 0.0013$, basal cover $p = 0.0099$). *L. dalmatica* density was significantly greater in the postsettlement removed canopy type than the postsettlement retained canopy and grass cover types ($p = 0.0273$). *L. dalmatica* biomass was significantly greater in the postsettlement removed canopy cover type than all three other cover types ($p = 0.0066$). Based on these results, restoration practices of thinning and prescribed burning will increase *L. dalmatica* cover, density, and biomass most severely in areas of heavy thinning.
9. We examined the relationship of *L. argenteus*, *B. tricholepis*, and *L. dalmatica* growth and reproduction to light intensity and forest floor depths. Light intensity had the greatest positive effect on *L. argenteus* aerial cover, biomass, and density in the postsettlement retained canopy cover type. Forest floor depths had the greatest negative effect on *L. argenteus* biomass in the postsettlement retained canopy cover type. Light intensity had the greatest positive effect on *B. tricholepis* growth and reproduction in the grass cover type. Forest floor depths generally caused decreases in *B. tricholepis* growth and reproduction, but a specific canopy cover type was not favored. Light intensity did not have a significant effect on *L. dalmatica* plant growth or reproduction except for height in the postsettlement removed canopy type. Forest floor depths had a generally positive effect on *L. dalmatica* growth and reproduction in the presettlement, postsettlement removed, and grass cover types.
10. Germination response was 88 percent for *B. tricholepis*, 70 percent for *B. tectorum*, 56 percent for *L. argenteus*, and 43 percent for *L. dalmatica*. Viability

was greatest for *L. argenteus* (94%), but 38 percent were considered hard seed, probably requiring scarification, and did not germinate. *L. dalmatica* and *B. tectorum* had the greatest percentage of dead seed (57% and 29%, respectively

More autoecological studies are needed to develop a base of information fror which restorationists can draw when restoring understory systems. Findings from th research provide clues toward the restoration of selected species, and may also provide insight regarding mechanisms influencing response of co-occurring species. These findings help restorationists manage for native species such as *L. argenteus*, where increased soil nitrogen is desired, and *B. tricholepis* where native C_4 grass increases are needed. These findings may also help mitigate noxious weed invasior where thinning and prescribed burning is proposed.

Results from this study provide land managers with information on growth an reproduction of *Lupinus argenteus*, *Blepharoneuron tricholepis*, and *Linaria dalmatic* not previously available. This research provides clues to managers for implementing restoration treatments that may maximize development of the native understory community in southwestern ponderosa pine forests, and hopefully minimize the invasion of noxious weeds.

CHAPTER 1

INTRODUCTION

Forest ecosystems throughout the Southwest have undergone many changes since the introduction of land use practices such as livestock overgrazing, harvesting of old-growth trees, and fire suppression associated with Euro-American settlement in the late nineteenth century (Arnold 1950, Cooper 1960, Savage et al. 1996, Covington et al. 1997). Altered forest structure and function have led to many critical conservation problems including loss of native biological diversity, declining herbaceous and woody plant production, and higher mortality rates of old-growth trees (Kolb et al. 1994, Biondi 1996, Mast et al. 1999). In the absence of naturally-occurring low intensity surface fires over the past century, forests have become unnaturally dense with small diameter pine thickets, forest floor fuels have accumulated, and herbaceous and shrub production have decreased (Arnold 1950, Cooper 1960, Swetnam and Betancourt 1990, Covington and Moore 1994 a, b; Kolb et al. 1994, Swetnam and Baisan 1994, Covington et al. 1997, Moore et al. 1999).

Reversing such changes and restoring more nearly natural conditions that are characteristic of the evolutionary environment of an ecosystem are basic concepts in restoration ecology (Society for Ecological Restoration 1993). The modern land management paradigm of ecosystem management is closely linked to ecological restoration because it is based on the best possible understanding of the structure, function, and composition of intact, natural ecosystems as a point of reference for management strategies (Kaufmann et al. 1994). "Restoring" ecosystems encompasses a variety of possible treatments, ranging from restoring native ecosystem components (for example, re-introducing an extirpated species or thinning trees to recreate an open forest structure) and natural disturbances (fires, floods, etc.) to removing exotic species that negatively affect natives. In order to restore natural ecosystem function and structure to northern Arizona ponderosa pine (*Pinus ponderosa* P.& C. Lawson var. *scopulorum* Engelm.) forests, detailed information on specific plant responses to restoration treatments is needed. Not only will this information provide clues toward the restoration of selected species, but it may also provide insight regarding mechanisms influencing response of co-occurring species or aggressive non-native ones.

In this study, we determined the effects of thinning and prescribed burning on phenology, growth, and reproduction of two common native and one aggressive non-native understory plant species in northern Arizona. The species studied were *Lupinus argenteus* Pursh, *Blepharoneuron tricholepis* (Torr.) Nash, and *Linaria dalmatica* (L.) P. Mill. We also collected mature seeds of the aforementioned species, plus *Bromus tectorum* L., to determine some basic germination rates. Phenology, growth, reproduction, and seed germination are traits that are under heavy selection pressure for plant survival and therefore, it is critical to understand their response to restoration treatments. Plants allocate resources to growth, maintenance, and reproduction (Barbour et al. 1999) depending on environmental and genetic constraints (Ffolliott and Clary 1975, Primack 1980, Menke and Trlica 1981, Ollerton and Lack 1998). We examined phenology, growth, and reproduction of plants in a

thinned only treatment, a thinned plus burned treatment, and a control treatment. Light intensity (PAR) and forest floor fuel loads were also examined in each treatmer to explore the influence of environmental variables on plant growth and reproduction

Results from this study provide managers with information that will maximize development of the native understory community, determine the time for seed collection, and provide insight into the control of an aggressive non-native species ir areas undergoing thinning and prescribed burning treatments.

PLANT BIOLOGY

The specific native plant species we examined were *Lupinus argenteus* Pursh (silvery lupine) and *Blepharoneuron tricholepis* (Torr.) Nash (pine dropseed). Both species are good candidates for use in restoration or revegetation projects because they are early colonizers with disturbance, yet continue to persist in more establishe ponderosa pine plant communities in the Southwest (L. Machina personal observation).

The aggressive non-native species, *Linaria dalmatica* (L.) P. Mill. (Dalmatian toadflax) was also examined. *Bromus tectorum* L. (cheatgrass) was removed from the study due to its low occurrence in ponderosa pine restoration sites in the Fort Valley area, where this study was conducted. *B. tectorum* occurs more often on highly disturbed sites, such as open roadsides and heavily grazed meadows, grasslands, and woodlands. Both species are listed as noxious weeds in the state o Arizona and threaten biodiversity of native ecosystems.

Lupinus argenteus Pursh (silvery lupine)

Lupinus argenteus, in the Fabaceae family, is one of the most common perennial lupines in the ponderosa pine, mixed conifer, and subalpine forest types ir the Southwest, and is prevalent throughout the Rocky Mountain States (Whitson et al. 1992). *L. argenteus* is an herbaceous legume native to much of the western United States and Alberta, Canada as well as Mexico, and grows in open stands of ponderosa pine at 2,134 to 3,048 meters (Pollock 2001).

Lupines are site colonizers and species in this genus respond rapidly after disturbance because they have nitrogen-fixing capabilities and reproduce both vegetatively (Mathews 1993) and by seed (Foster 1984). Its nitrogen-fixing symbioti root nodules make exchangeable nitrate and ammonium available to *L. argenteus* plants themselves as well as to the surrounding vegetation, allowing it to grow in po soils (Story 1974, Foster 1984, Kenny and Cuany 1990). Nodulation increases with elevation (Rumbaugh and Johnsen 1991), therefore, due to Flagstaff's 2134 meter-elevation, *L. argenteus* in our area may display even greater nitrogen-fixing benefits Story (1974) found that *L. argenteus* plants with symbiotic root nodules produced greater biomass and greater percentage plant nitrogen compared to *L. argenteus* plants without nodulation. Mathews (1993) examined two other lupine species (*L. sericeus* Pursh and *L. caudatus* Kellogg) that do not occur in northern Arizona. He

found that both species had an extraordinary ability to occupy poor site conditions. In addition, the post-fire regeneration strategy of both species is vegetative, emerging through growing points in the soil from a central caudex (Mathews 1993). *L. argenteus* is an early colonizer with deep taproots and rhizomes from a central caudex that may encourage survival after prescribed burns (Flinn and Wein 1977). Seedlings are prevalent on old roads and fire lines at the study site (L. Machina personal observation).

Germination information for *L. argenteus* does not exist, but in general, fresh seeds of lupine do not require pretreatment, but stored seeds require hot water or acid scarification (AOSA 1970). *L. polyphyllus* Lindl., using approximately 1,000 seeds per ounce, required 21-28 days to emerge at a temperature of 65-75°F (USDA 1961). Lastly, the USDA (1961) recommended that entire pods be stripped from the plant when in the medium to hard-dough stage for seed collection. However, we found this method to yield a very low percentage of viable seeds, and recommend netting plants and waiting for seeds to naturally drop out of pods.

L. argenteus is also is an important food source to wildlife and insects since new vegetative growth, flowers, seeds and seed pods are all eaten (Pollock 2001). However, the plant is potentially toxic to livestock especially when seed pods are developing (Panter et al. 1999). In northern Arizona, *L. argenteus* is considered a secondary poisonous plant to livestock (Schmutz et al. 1967). *L. argenteus* is considered an increaser with livestock grazing (Arnold 1950, Pollock 2001).

***Blepharoneuron tricholepis* (Torr.) Nash (pine dropseed)**

Blepharoneuron tricholepis (Torr.) Nash (pine dropseed) is a native perennial bunchgrass with C_4 photosynthetic pathway in the Poaceae family and the subtribe Muhlenbergiinae that reproduces by seed and tillers (Stubbendieck et al. 1994). It is endemic to the higher elevations (2,134 - 3,048 meters) of the southwestern U.S. and northern Mexico (Stubbendieck et al. 1994). Pine dropseed was originally named *Vilfa tricholepis* Torr. by Torrey in 1857, then transferred to the genus *Sporobolus* by Coulter (1885), and finally, Nash (1898) proposed the generic name *Blepharoneuron*.

B. tricholepis is a good candidate for restoration or revegetation projects because it is an early colonizer with disturbance, yet is persistent in thriving native understory communities beneath mature *P. ponderosa* stands in the Southwest (author's personal observation). *B. tricholepis* seedlings occur on old roads and fire lines at the study site (author's personal observation).

The species, especially when young, is highly palatable to ungulates such as deer, elk, cattle and sheep, and should be part of the plant composition when ranges are in good condition (Judd 1962). *B. tricholepis* is considered an increaser with livestock grazing (Arnold 1950).

Few studies have been conducted on this species. Pearson (1942) conducted a clipping study in which grassy plots dominated with *Festuca arizonica* Vasey (Arizona fescue) were clipped twice yearly during a 10-year period. Pine dropseed and *Muhlenbergia montana* (Nutt.) A.S. Hitchc. (mountain muhly) increased, while *F. arizonica* decreased with clipping to a two-inch height. Pearson's study suggests that

pine dropseed could be an increaser with grazing. Kerns et al. (2001) studied grass phytoliths in the soil and also suggested that pine dropseed may be an increaser wit grazing. There are no previous phenological studies or germination tests for pine dropseed (Willey 1999). We do know, however, that pine dropseed has a C_4 photosynthetic pathway and initiates growth through basal leaves in April-May, then flowers and sets seed in September. Since pine dropseed is closely related to the *Sporobolus* genus, we used germination requirements from species of *Sporobolus* a surrogates until we learned more about pine dropseed. Seeds for *S. cryptandrus* (Torr.) Gray require 5 days of cold, moist stratification before incubation with light ar KNO_3 enrichment (Toole 1941). Pollock and Toole (1961) suggest that chemical scarification may be needed for dropseed grasses. Jackson (1928) tested seeds of *airoides* (Torr.) Torr. and *S. giganteus* Nash. Both of these species have at least a 40% seed germination rate.

Linaria dalmatica (L.) P. Mill. (Dalmatian toadflax)

Linaria dalmatica (L.) P. Mill. (Dalmatian toadflax) is an aggressive exotic for in the Scrophulariaceae family, and is considered an important weed of rangelands and croplands, especially in western North America. It is listed as a restricted noxio weed in the state of Arizona (USDA, 2001). The literature on this species is less extensive than for *Linaria vulgaris* Nash. Dalmatian toadflax is a perennial plant fror southeastern Europe. It reproduces by seed and underground rhizomes. During the first year of growth only a few flowing stalks are produced, but up to 25 stalks can b produced each of the following years (Saner et al. 1994). The larger individuals ma produce up to a half million seeds per year and spring germination is typical (Saner al. 1994). In addition, the plant has a deep, extensive root system allowing fire-adaptation, and, together with its waxy leaves, makes it difficult to control (Whitson al. 1992). It out-competes native plant species and decreases plant diversity (Whitson et al. 1992). Fresh seeds of *Linaria* may require cold-moist stratification fo maximum germination response (AOSA 1970). *L. vulgaris* requires light for germination, and approximately 50% germination was obtained with incubation at 6 80°F for 14 days with this species (Lincoln 1983). *L. maroccana* Hook f. required 14 21 days for emergence at 65-75°F (USDA 1961).

Bromus tectorum L. (cheatgrass)

Although *Bromus tectorum* L. (cheatgrass) was removed from this study, however, we will include information about cheatgrass because preliminary data we collected for this species. Seed collection and one germination trial for cheatgrass was conducted. There is an extensive literature on cheatgrass (Finnerty and Klingman 1962, Young and Evans 1978, Mack 1981, Morrow and Stahlman 1984, Milby and Johnson 1987, Young and Tipton 1990, Melgoza et al. 1990, Pierson anc Mack 1990, Pierson et al. 1990, Novak et al. 1991, Monsen 1994, Beckstead et al. 1995, Beckstead et al. 1996, Novak and Mack 2001). In general, it is an aggressive

exotic, winter annual grass in the Poaceae family that has a broad geographic range. Once established in an area, cheatgrass competes very effectively with the native plants and reduces the species diversity (Young and Evans 1978, Morrow and Stahlman 1984, Melgoza et al. 1990). Less attention has been placed on cheatgrass in forested habitats, although Pierson and Mack (1990) studied the effect of tree canopy, understory, herbivores, and litter depth on the seedling establishment, survival, and reproduction of this species in several forest habitats in western North America. They did not notice increased recruitment, survival, or reproduction of cheatgrass in clearcut ponderosa pine forests unless the understory plant community was also disturbed. In addition, increasing litter depth negatively influenced the germination and recruitment of cheatgrass. Since cheatgrass is a winter annual, the seeds ripen and are dispersed in early summer, but do not germinate until autumn (Beckstead et al. 1996). However, in northern Arizona, cheatgrass plants flower and scatter seed twice per growing season, once in the late spring/early summer, then again in the fall (L. Machina personal observation). Much research has been conducted on cheatgrass germination (Milby and Johnson 1987, Beckstead et al. 1995, Beckstead et al. 1996). Milby and Johnson (1987) found a variety of results ranging from failed germination at high temperatures, high percentages of germination in fresh seeds collected in the fall (>90% under a variety of temperatures), and finally, delayed germination. This study and others suggest that local information on phenology and germination responses are necessary for wise management decisions and control of cheatgrass.

RESEARCH HYPOTHESES

We hypothesized that all three plant species would exhibit greater growth and reproduction on sites that were restored. Compared to the control, plants in the treated sites should have greater growth and reproduction due to decreased fuel loads, and increased light, soil moisture, and disturbance from overstory thinning and frequent fire. We also hypothesized that the control treatment with greater tree densities and canopy cover would have greater forest floor depths and less available light and soil moisture, and thus be a more stressful environment for all three species. Therefore, we expected lower growth and reproduction in control plants.

We also explored the relationships of species' growth and reproduction under different forested conditions. We hypothesized that growth and reproduction would respond positively to increased light intensity, and negatively to increased forest floor depths. Additionally, we hypothesized that growth and reproduction characteristics are consistent with one another, meaning that increases in growth are associated with increases in reproduction.

Results from this study provided land managers with information on growth and reproduction of *Lupinus argenteus*, *Blepharoneuron tricholepis*, and *Linaria dalmatica* not previously available. This research provided clues to managers for implementing restoration treatments that may maximize development of the native understory community in southwestern ponderosa pine forests, and hopefully minimize the invasion of noxious weeds.

OBJECTIVES

Objective 1. To quantify the phenological, growth, and reproduction responses of three herbaceous understory plant species (silvery lupine, pine dropseed, and Dalmatian toadflax) to various restoration treatments in the ponderosa pine forests c northern Arizona.

Objective 2. To collect seeds of four herbaceous understory plant species (silvery lupine, pine dropseed, Dalmatian toadflax, and cheatgrass) for germination trials, ar to add to the body of knowledge on plant seed collection in northern Arizona. [Note: in 2000 cheatgrass was removed from this study].

Objective 3. To conduct germination tests on these four species to determine germination percentages.

CHAPTER 2

METHODS

STUDY SITES

There are two study sites for this project. Both are located in or near the Fort Valley Experimental Forest within the Coconino National Forest and are shown in figure 1. Studies of *Lupinus argenteus* and *Blepharoneuron tricholepis* were conducted within the Gus Pearson Natural Area (GPNA) on the Fort Valley Experimental Forest and the Coconino National Forest, 12 km northwest of Flagstaff. It is an area of the GPNA that was decommissioned in 1992 and a set of experimental restoration treatments initiated (Covington et al. 1997). The experimental treatments included thinning from below, thinning from below and prescribed burning, and a control. Figure 2 shows an aerial view of a stem map for GPNA after treatments were implemented. Note the high density of trees in the control compared to low, patchy density in the partial and full treatments.

Linaria dalmatica research was conducted on the Coconino National Forest in the Flagstaff Urban-Wildland Interface (FUWI), 9 km northwest of Flagstaff, shown in figure 3. Studies were conducted within Experimental Block 3 (EB3), specifically in EB3-1 (control treatment) and EB3-2 (heaviest thinning from below plus prescribed burning treatment).

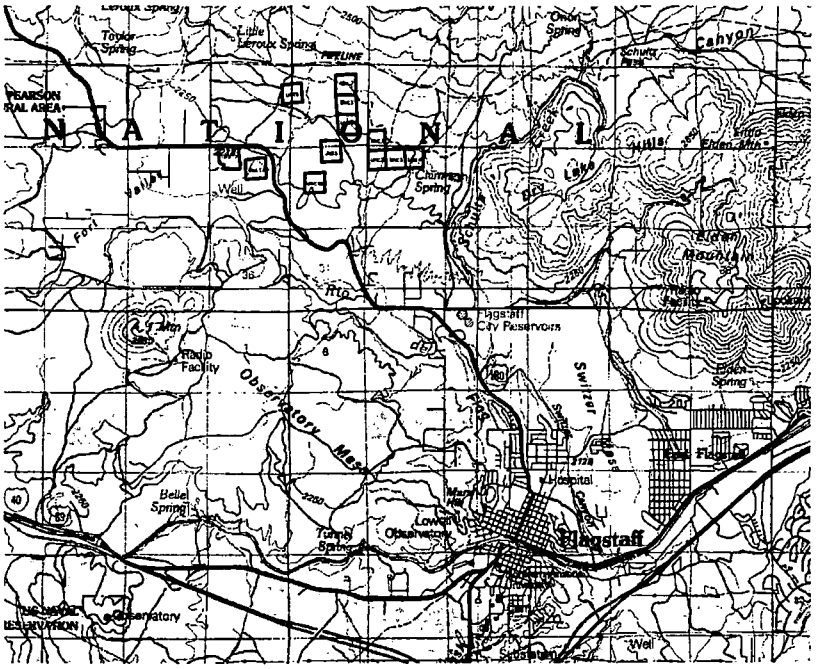


Figure 1. Topographic map of the Flagstaff area and Fort Valley Experimental Forest surrounded by the Coconino National Forest. Both study sites are shown. Gus Pearson Natural Area (GPNA) is in the northwest corner of the map. The Flagstaff Wildland-Urban Interface (FUWI) is located just to the east of GPNA across Highway 180.

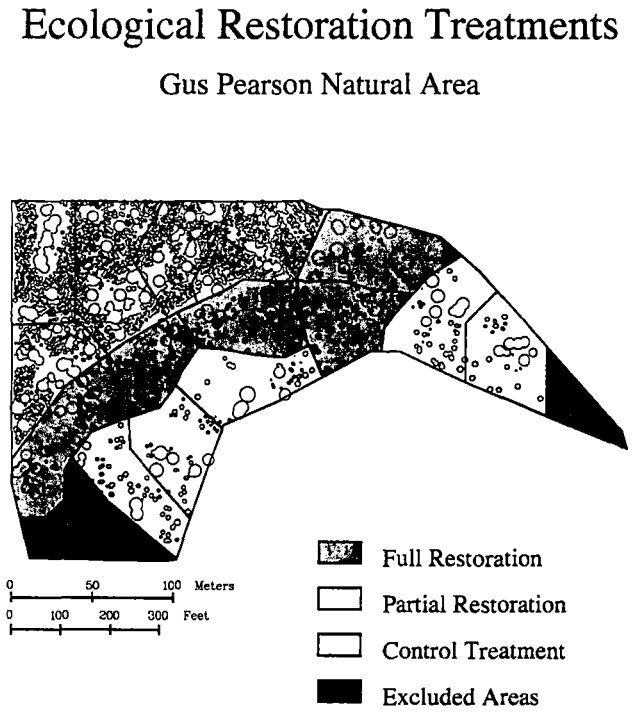


Figure 2. Aerial view of a stem map of the GPNA restoration treatments. Stem map was constructed after thinning treatments were implemented in 1993 (Covington et al. 1997). Note dense trees in control.

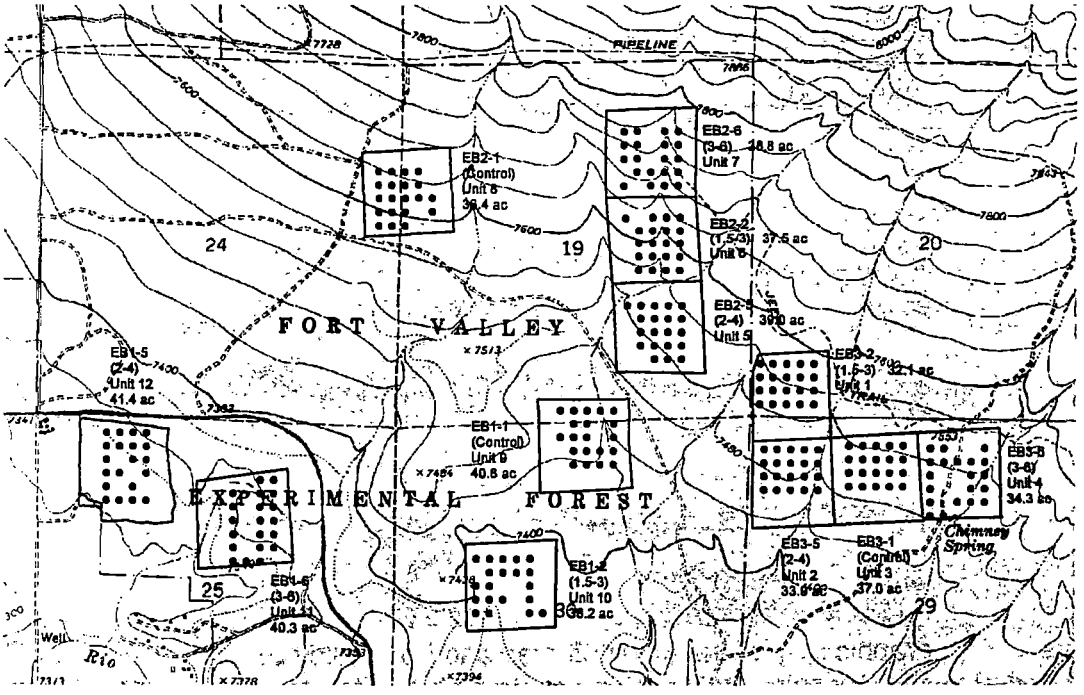


Figure 3. Topographic map of the FUWI study site including EB1, EB2, and EB3. EB3-1 and EB3-2 are the specific sites where *Linaria dalmatica* research was conducted.

SAMPLING

At GPNA, plants were monitored in three of five replicates per treatment based on adequate presence of *Lupinus argenteus* and *Blepharoneuron tricholepis* plants. All *L. argenteus* and *B. tricholepis* plants within these three replicates were located and marked, and approximately one-third were randomly selected for study. At FUWI, *Linaria dalmatica* plants were monitored within each of the two treatments, and chosen in the same manner as GPNA plants. One $1m^2$ circular plot was established around each *L. argenteus*, *B. tricholepis*, or *L. dalmatica* "indicator plant." A total of 152 *L. argenteus* $1m^2$ plots were established, including approximately 17 plots per replicate and 50 plots per treatment. A total of 146 *B. tricholepis* $1m^2$ plots were established, including approximately 16 plots per replicate and 48 plots per treatment. A total of 69 *L. dalmatica* $1m^2$ plots were established, including 30 control plots and 39 treatment plots. Circular plots were permanently marked and an indicator plant on each plot was selected and tagged in order to follow plants throughout the 1999-2001 growing seasons.

Overstory canopy types were determined for each $1m^2$ plot. The overstory canopy types are: 1) presettlement, in which the canopy of a presettlement tree occurs above the plot, 2) postsettlement-retained, in which the canopy of a postsettlement tree occurs above the plot, 3) postsettlement-removed, in which no tree canopy cover occurs above the plot because postsettlement trees were removed in the restoration thinning, and 4) grass, in which no tree canopy cover occurs above the plot because grasses dominated prior to restoration treatments. Note that the postsettlement-removed canopy type occurs in the restoration treatments only because tree removal did not occur in the control treatments. The grass cover type, presettlement tree canopy cover type, and postsettlement-retained canopy cover type occur in all three treatments. The grass cover type is dominated by grasses, and is probably quite similar in all three treatments because it is required that no tree canopy occur directly over top. The presettlement tree canopy cover type is dominated by presettlement ponderosa pines, and is probably quite similar in all three treatments because it is required that tree canopy above the plot is from presettlement trees only. Therefore, postsettlement tree densities should not affect tree canopy cover over both cover types. The postsettlement-retained canopy type, however, must have postsettlement tree canopy above the plot. In the control treatment, this canopy type is probably more dominated by postsettlement trees than in the partial and full treatments, where thinning occurred.

Phenological data were collected by observing plants from each species for one entire growing season. Phenophases were produced for each indicator plant every two weeks throughout each growing season. When in reproductive phenophases, phenophases were recorded for each reproductive stalk, and stalks were counted. To calculate average phenophase per treatment at each collection date, the most mature phenophase (i.e., the greatest phenophase number) for each indicator plant was used to calculate an average phenophase per treatment.

Seasonal plant growth is the increase in increment in dry mass, volume, length, or area (Lambers et al. 1998). Maximum height, cover, and aboveground biomass were the variables selected to estimate seasonal plant growth. Number of

stems was also measured for *L. dalmatica*. Indicator plant height (cm) was measure from ground level to the tallest part of the plant periodically during reproductive phenophases to determine peak seasonal height. Biomass data were collected in 2001. A subset of plants were clipped so that other measurements could continue until the end of the growing season.

Aerial cover (cm) was determined on both *L. argenteus* and *L. dalmatica* by measuring the aerial diameter at the widest part of each indicator plant, then taking second aerial diameter measurement perpendicular to the first measurement throug the center of the plant. Both diameter lengths were averaged to determine one aeria cover measurement. Basal cover (mm) was determined on *B. tricholepis* by measuring the widest basal diameter of each bunchgrass indicator plant using digita calipers, then taking a second basal diameter measurement perpendicular to the firs measurement through the center of the plant. Both diameter lengths were averaged to determine one basal cover measurement. Note that *L. argenteus* cover in the yea 1999 is a basal (stem) cover measurement in millimeters, and in the years 2000 anc 2001, it is an aerial cover measurement in centimeters. We present results from the 1999 *L. argenteus* basal cover data, but modified methods in 2000 and 2001 to mor accurately capture cover information for the forb. Both basal and aerial cover were measured on *L. dalmatica* plants. Basal cover was measured on *L. argenteus* in lieu of aerial diameter in 1999. Both basal and aerial diameter cover were measured on *dalmatica* plants in 2001. Basal cover was measured on *L. dalmatica* plants becaus the basal diameter seems to be related to the number of stalks, which we counted o each *L. dalmatica* indicator plants. *L dalmatica* stalks grow at ground level at the base of plants. Aerial and basal cover are referred to as "cover" throughout this report.

Aboveground biomass (g) was determined by clipping plants at ground-level for *L. argenteus* and *L. dalmatica*, and at stubble-height for *B. tricholepis*. At GPNA, we clipped eight randomly selected indicator plants per replicate (24 per treatment) peak production, just after plants reached peak reproduction. At FUWI, we clipped 1 *L. dalmatica* plants per treatment. Clipped plants were oven-dried at 70 °C for a 48-hour period, and weighed.

Reproduction data were collected by counting the number of reproductive stalks on indicator plants and determining the phenophase of each reproductive stal every two weeks of the reproductive period. To calculate average reproductive stalk per indicator plant, reproductive stalks counted on plants were summed in each replicate, then divided by the total number of plants in that replicate.

Other plant data collected included measuring local density by counting all *L. argenteus*, *B. tricholepis*, or *L. dalmatica* plants on each $1m^2$ plot, and measuring average height (cm) of all *L. argenteus*, *B. tricholepis*, or *L. dalmatica* plants on eac $1m^2$ plot.

Environmental data were collected at both study sites, and included light intensity and forest floor depth. To quantify light availability on $1m^2$ plots, a ceptometer was employed to measure photosynthetically active radiation, or PAR ($\mu mols/m^2/sec$). PAR data were collected between 8-10 am, 11 am-1 pm, and 3-5 p near the summer solstice in 2001. Due to monsoon rains, the 3-5 pm PAR

measurement of *L. dalmatica* plants was not obtained. Litter and fermentation + humus depths (in) were measured at plot centers using a ruler.

Seed collection permits were obtained from the USDA Forest Service for the Coconino National Forest and for the Fort Valley Experimental Forest. Seeds of the original four plant species were collected from September-November, 1999. Seed collection was focused mostly in the Fort Valley Experimental Forest and the Coconino National Forest along Highway 180. Seed collection and processing of each species is discussed in results and discussion.

Seeds collected in 1999 were stored at room temperature until August 2000 at which time seeds were cleaned, sorted, counted, weighed, and sent to the Arizona State Seed Testing Lab in Phoenix for standard germination testing (Willey 1999, 2000). Excess seeds collected in 1999 were stored in the cold room at 5 °C to examine storage methods.

STATISTICAL ANALYSES

An analysis of variance (ANOVA) tests for differences in a dependent response variable between independent populations (Ott 1993). ANOVAs were used to compare growth, reproduction, and environmental variables between treatments using all available data. An example null hypothesis follows (note only one dependent variable):

$$Ho: \mu_{PAR1} = \mu_{PAR2} = \mu_{PAR3}$$

Where, PAR = Light Intensity
1 = Control Treatment
2 = Partial Treatment, and
3 = Full Treatment

If the null hypothesis of equality between treatments was rejected, the Tukey-Kramer HSD (honestly significant difference) test was used to determine which treatment means were significantly different from each other.

An alpha level of 0.10 was chosen for the ANOVAs to offset the low number of replicates (n = 3) used per treatment in the GPNA study of *L. argenteus* and *B. tricholepis* (Ott 1993). Control, thin only, and thin plus burn treatments were applied before *L. argenteus* or *B. tricholepis* $1m^2$ plots were established. Although data were collected on approximately 50 *L. argenteus* plots per treatment, for example, treatments were applied randomly to replicates, not $1m^2$ plots. Therefore, it was necessary to average approximately 17 individual plant or plot measurements within each replicate to create three replicate means per treatment that were used in analyses. Similar studies use an alpha value of 0.10 to compensate for low sample sizes (Armour et al. 1984, Wright and Hart 1997, Hart et al. 1997, Kaye and Hart 1998, Feeney et al. 1998).

At FUWI, ANOVAs were conducted to test for differences between measured variables of *L. dalmatica* plants and plots. An alpha level of 0.05 was chosen, and a student's t-test was used if differences were detected. Because there were two

treatments used (thin plus burn and control) with no replication, n = 30 in the contro and n = 39 in the thin plus burn treatment.

Repeated measures analysis of variance (Ott 1993) was used to test the hypothesis that plant phenology was different between treatments over time. Phenophases were measured on indicator plants every two weeks throughout each growing season. Mean phenophase per plant was calculated in each treatment at each collection date, and plotted over time. A date by treatment interaction for phenology was tested.

Repeated measures analysis of variance (Ott 1993) was also used to test the hypothesis that the mean number of reproductive stalks per plant was different between treatments over time. The number of reproductive stalks per plant was counted every two weeks throughout each reproductive period. Mean number of reproductive stalks per plant was calculated in each treatment at each collection date, and plotted over time. A date by treatment interaction for number of reproductive stalks was tested.

We also used repeated measures analysis of variance (Ott 1993) to compare *L. argenteus* and *B. tricholepis* height, cover, and density each in 1999, 2000, and 2001 to test if each of these variables was different between treatments over the three years of study.

Correlation analyses and regression analyses were conducted on 2001 *Lupinus argenteus* and *Blepharoneuron tricholepis* data only to examine relationshi between growth, reproduction, and environmental variables. Simple linear regressic was used to determine if variability in plant height, cover, biomass, and reproductior could be explained by light intensity (PAR), litter depths, or fermentation + humus depths on plots. For example:

$$y = \beta_o + \beta_1 x + \varepsilon$$

Where, y = dependent variable; either height, cover, biomass, # reproductive stalks, or density
x = independent variable; either morning PAR, midday PAR, afternoon PAR, average daily PAR, litter depth, fermentation + humus depth, or l + f + h depth
β_o = y-intercept
β_1 = slope of the straight line
ε = random error

Then, multiple regression was used should several environmental variables prove to be significant. Multiple regression analysis were also used to predict the number of reproductive stalks per plant using growth variables to test if growth and reproduction are consistent. For example:

$$y = \beta_o + \beta_1 x_1 + \beta_2 x_2 + \varepsilon$$

Where, y = response variable; # reproductive stalks
X_1 = independent variable 1; cover
X_2 = independent variable 2; biomass
β_o = y-intercept
β_1 = slope of the straight line
ε = random error

Data from all three treatments at GPNA were lumped to determine correlation and regression relationships between plant growth, reproduction, and environmental data so that the total number of replications used in the analysis was equal to approximately 150 instead of 3 as in the ANOVAs. Regression analyses also included separating data into overstory canopy types to assess how light intensity and forest floor depths affected *L. argenteus* and *B. tricholepis* growth and reproduction. An alpha level of 0.05 was chosen for correlation and regression analyses. JMP in Version 4.0.4 (academic) was used for all analyses (SAS Institute Inc, 1989 – 2001).

CHAPTER 3

RESULTS AND DISCUSSION OF OBJECTIVE 1:

Plant Phenology, Growth, and Reproduction Responses in Ponderosa Pine Forest Restoration in Northern Arizona

Objective 1. To quantify the phenological, growth, and reproduction responses of three herbaceous understory plant species (*Lupinus argenteus*, *Blepharoneuron tricholepis*, and *Linaria dalmatica*) to various restoration treatments in the ponderos pine forests of northern Arizona.

PHENOLOGY

Table 1 shows the phenophases observed in *Lupinus argenteus*, *Blepharoneuron tricholepis*, and *Linaria dalmatica*. All three species were observed for an entire growing season before phenophases were finalized. Note that the gras *B. tricholepis* has only one vegetative phenophase before reproductive phases beg compared with three and four vegetative phenophases in the forbs, *L. dalmatica* an *L. argenteus*, respectively.

Table 1. Phenophases observed in *Lupinus argenteus*, *Blepharoneuron tricholepis*, and *Linaria dalmatica*.

silvery lupine ***Lupinus argenteus*** **Native**	**pine dropseed** ***Blepharoneuron tricholepis*** **Native**	**Dalmatian toadflax** ***Linaria dalmatica*** **Invasive non-native**
0 = died	0 = died	0 = died
1 = winter dormancy/dead	1 = winter dormancy/dead	1 = winter dormancy/dea
2 = emergence (leaves closed)	2 = new leaves, regreening	2 = emergence, regreeni
3 = leaves open	3 = culm emergence	3 = stem elongation
4 = stem elongation	4 = spikelet formation	4 = branching of stem
5 = branching of stem	5 = anthesis	5 = flower bud developm
6 = flower bud development	6 = green seed	6 = flowering
7 = flowering	7 = hard seed	7 = seed set
8 = flowers/pods fell off, either a) flowers not pollinated, b) seed pod not yet emerged, or c) seed pods shattered	8 = seed shatter (>1/2 seeds shattered)	8 = seed shatter
9 = seed pod formation (green doughy pod)	9 = dieback/dormancy	9 = fall regrowth
10 = seed set		10 = dieback/dormancy
11 = seed shatter		
12 = fall regrowth		
13 = dieback/dormancy		

Figures 4, 5, and 6 show average phenophases per treatment of each species during the 2001 growing season. The most mature phenophase of each indicator plant was used to create an average phenophase at each data collection date. Because phenophase numbers increase with increasing plant maturity, we were able to statistically compare average phenophases across dates using repeated measures analyses. All three species, displayed significant date by treatment interactions in the year 2001 (*L. argenteus*, $p < 0.0001$, *B. tricholepis*, $p < 0.0001$, *L. dalmatica*, $p = 0.02169$).

In all three species, the control plants had the lowest average phenophases during the reproductive periods. This is, in part due to a lower percentage of control plants reaching reproductive maturity (Machina, 2003). Early in the growing season, *L. argenteus* average phenophases in the control were slightly greater than treatment plants, as shown in figure 4. Control plants came out of winter dormancy and began to grow slightly earlier than treatment plants. Often, plants in stressed environments will respond to limited resources by maturing quickly so that available resources are more likely to be used in reproduction than vegetative growth (Bazzaz et al. 1987).

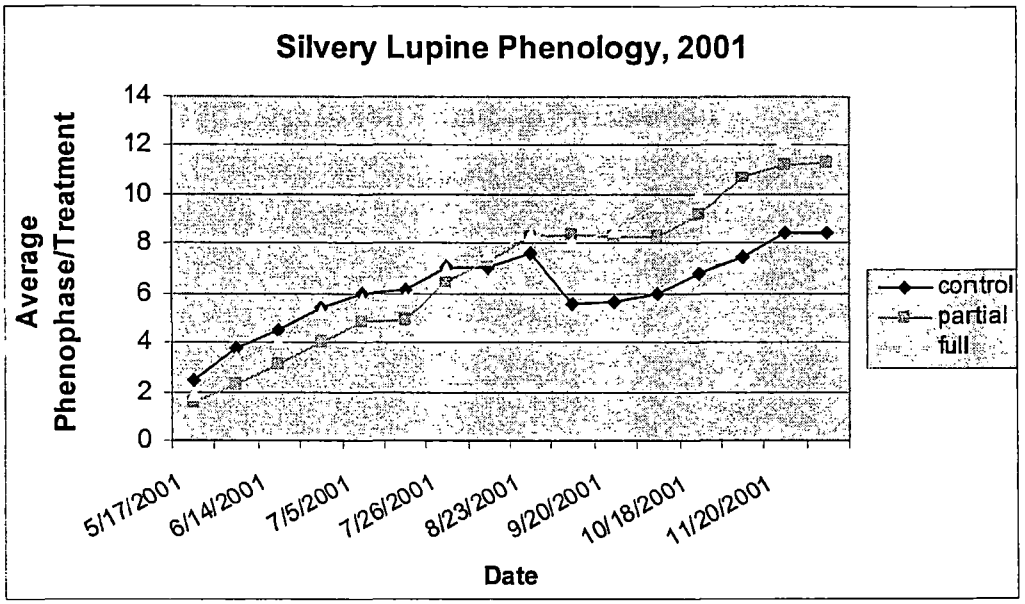


Figure 4. Average phenophases per data collection date of *Lupinus argenteus* at the GPNA study site in 2001. Repeated measures analysis showed a significant date by treatment effect in phenology of *L. argenteus* ($p < 0.0001$).

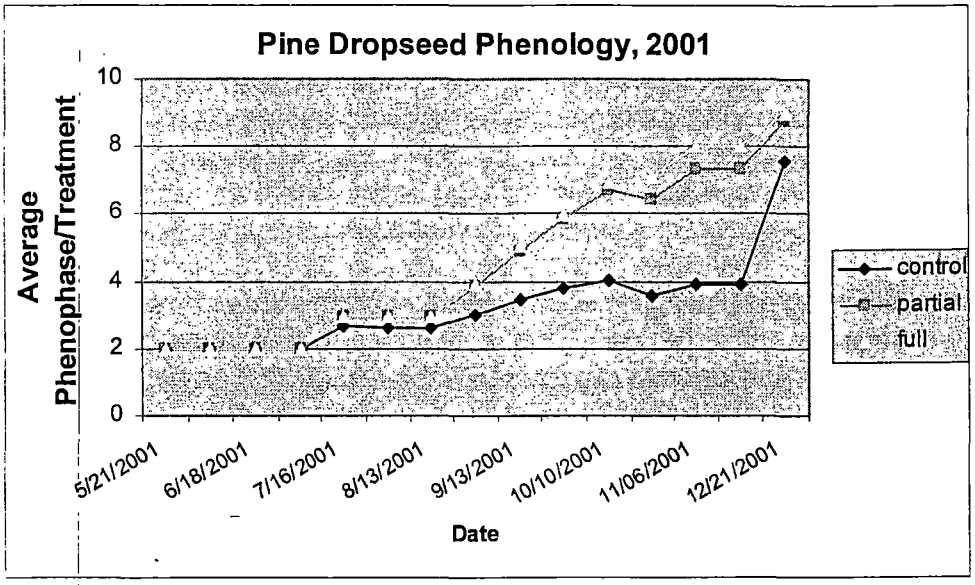


Figure 5. Average phenophases per data collection date of *Blepharoneuron tricholepis* at th GPNA study site in 2001. Repeated measures analysis showed a significant date by treatment effect in phenology of *B. tricholepis* ($p < 0.0001$).

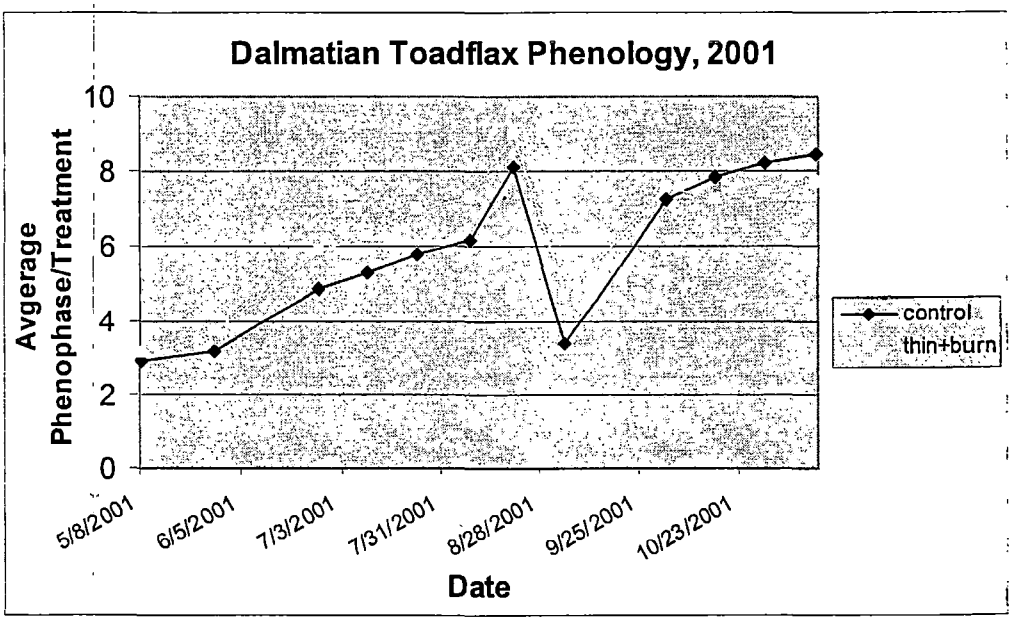


Figure 6. Average phenophases per data collection date of *Linaria dalmatica* at the GPNA study site in 2001. Repeated measures analysis showed a significant date by treatment effect in phenology of *L. dalmatica* ($p = 0.0217$).

GROWTH AND REPRODUCTION

Tables 2, 3, and 4 show growth and reproduction results for *Lupinus argenteus*, *Blepharoneuron tricholepis*, and *Linaria dalmatica*, respectively. Within each year, ANOVAs were conducted to determine if differences occurred between treatments for each species in a given growing season. Tables 2 and 3 show *L. argenteus* and *B. tricholepis* growth and reproduction data from 1999, 2000, and 2001, respectively. Table 4 shows *L. dalmatica* growth and reproduction ANOVA results for the year 2001 only. Between-year comparisons were conducted using repeated measures analyses to show if there were significant year by treatment interactions. Most of the results displayed in tables 2, 3, and 4 are shown in graphical form and discussed throughout this chapter in separate sections.

Table 2. *Lupinus argenteus* ANOVA summary comparing variables in the control, partial and full treatments at GPNA in 1999, 2000, and 2001, respectively. Measurements compared on a per plant basis are height, cover, aboveground biomass, and # reproductive stalks. Percent (%) of plants flowering, % plants producing seed, and % flowering plants producing seed are also shown. Measurements compared on a per $1m^2$ plot basis are average height and local density of plants on plots. Different lower case letters after treatment values indicate that means are significantly different (in bold). $\alpha = 0.10$, $n = 3$, approximately 50 plants. When data from all three years are shown, repeated measures analyses are presented in the row below ANOVAs.

Lupinus argenteus	**Year**	**Control**	**Partial**	**Full**	**p-value**
Max Height (cm)	1999	31.397a	31.8336a	28.9316a	0.4855
Max Height (cm)	2000	11.7566a	16.7724a	12.8536a	0.2317
Max Height (cm)	2001	31.4899a	36.3745a	31.5019a	0.4191
Yr X Trt Interaction	ns, p = 0.6285				
Basal Cover (mm)	1999	3.7071ab	**2.8825a**	**4.4517b**	0.0229
Aerial Cover (cm)	2000	**6.5548a**	**13.6206b**	11.4906ab	0.0612
Aerial Cover (cm)	2001	**22.7761a**	**34.9914b**	31.8898ab	0.0476
Yr X Trt Interaction	ns, p = 0.3224 (2000 & 2001 only)				
# Reprod Stalks/Plant	1999	4.0458a	5.2122a	5.8696a	0.7324
# Reprod Stalks/Plant	2000	0.1333a	0.5756a	0.2596a	0.1043
# Reprod Stalks/Plant	2001	**4.2212a**	**20.7266b**	16.2542ab	0.0602
Yr X Trt Interaction	**Significant, p = 0.0108**				
Density (# plants/plot)	1999	**3.6767a**	**3.5935a**	**11.2456b**	0.0021
Density (# plants/plot)	2000	**1.6746a**	**2.5041a**	**4.5583b**	0.0153
Density (# plants/plot)	2001	2.4767a	2.3271a	4.4597a	0.0972
Yr X Trt Interaction	**Significant, p < 0.0001**				
Biomass (g), 24 plants	2001	**3.0073a**	**13.2813b**	11.6277ab	0.0496
Plants Reproductive (%)	2001	68.5185a	92.3747a	93.7500a	0.1057
Plants Producing Seed (%)	2001	52.8571a	65.2097a	68.9815a	0.6709
Flwrg Plants Prod Seed (%)	2001	73.6310a	70.1389a	73.7892a	0.9604
Avg Height on Plots (cm)	2001	25.7983a	24.8525a	22.5600a	0.7335

Year by Treatment Interactions

Growth and reproduction of *L. argenteus* and *B. tricholepis* were lowest in 2000, which was a severe drought year. Growth and reproduction of *L. argenteus* were most affected by the 2000 drought year, and in effect, were most affected by yearly variations. Shown in table 2, there were significant year by treatment interactions for *L. argenteus* number of reproductive stalks ($p = 0.0108$, see also figure 16) and density ($p < 0.0001$, see also figure 23). Shown in table 3, *B. tricholepis* growth was more stable between years, however, number of reproductiv stalks had a significant year by treatment interaction ($p = 0.0602$, see also figure 18

L. argenteus dies down to the ground each year, and completely new aboveground plant material is generated each growing season. Compare this type c growth with *B. tricholepis*, a bunchgrass with basal vegetative parts that remain dormant throughout each winter, and change little in shape or size from

Table 3. *Blepharoneuron tricholepis* ANOVA summary comparing variables in the control, partial and full treatments at GPNA in 1999, 2000, and 2001, respectively. Measurements compared on a per plant basis are height, cover, aboveground biomass, and # reproductive stalks. Percent (%) of plants flowering, % plants producing seed, and % flowering plants producing seed are also shown. Measurements compared on a per $1m^2$ plot basis are average height and local density of plants on plots. Different lower case letters after treatment values indicate that means are significantly different (in bold). $\alpha = 0.10$, $n = 3$, approximately 50 plants. When data from all three years are shown, repeated measures analyses are presented in the row below ANOVAs.

Blepharoneuron tricholepis	**Year**	**Control**	**Partial**	**Full**	**p-value**
Max Height (cm)	1999	**55.2265a**	**68.4093b**	**66.4718b**	0.0025
Max Height (cm)	2000	**26.8756a**	**42.8657b**	**44.8325b**	0.0227
Max Height (cm)	2001	**38.2745a**	**61.4065b**	**59.6202b**	0.0044
Yr X Trt Interaction	ns, p = 0.1857				
Basal Cover (mm)	1999	48.9741a	61.9082a	64.5381a	0.0948
Basal Cover (mm)	2000	**42.2182a**	56.7090ab	**61.7423b**	0.0462
Basal Cover (mm)	2001	**46.3118a**	**67.3166b**	**69.6309b**	0.0116
Yr X Trt Interaction	ns, p = 0.1750				
# Reprod Stalks/Plant	1999	5.5294a	12.8221a	10.9804a	0.1433
# Reprod Stalks/Plant	2000	**1.5739a**	**9.7702b**	**11.9477b**	0.0141
# Reprod Stalks/Plant	2001	**3.5503a**	10.1321ab	**15.7791b**	0.0188
Yr X Trt Interaction	**Significant, p = 0.0672**				
Density (# plants/plot)	1999	12.6641a	6.0965a	11.9673a	0.5495
Density (# plants/plot)	2000	6.3804a	6.5614a	10.0118a	0.4912
Density (# plants/plot)	2001	4.3791a	5.5129a	8.5726a	0.3533
Yr X Trt Interaction	ns, p = 0.4471				
Biomass (g), 24 plants	2001	**1.6196a**	**3.9592b**	**4.2531b**	0.0191
Plants Reproductive (%)	2001	**64.8366a**	**96.1623b**	**98.0392b**	0.0022
Plants Producing Seed (%)	2001	**40.2615a**	**96.1623b**	**98.0392b**	0.0002
Reprod Plants Prod Seed (%)	2001	**61.8881a**	**100.0000b**	**100.0000b**	0.0051
Avg Height on Plots (cm)	2001	**26.4059a**	**44.8843b**	**44.6496b**	0.0027

Table 4. *Linaria dalmatica* ANOVA summary comparing variables in the control and thin plus burn treatment at FUWI in 2001. Measurements compared on a per plant basis are height, cover, aboveground biomass, and # reproductive stalks. Local density of plants on plots is compared on a per $1m^2$ plot basis. Different lower case letters after treatment values indicate that means are significantly different (in bold). $\alpha = 0.05$, n = 30 (control), n = 39 (thin+burn).

Linaria dalmatica	Date	Control	Thin + Burn	p-value
Max Height (cm)	2001	51.9667a	60.8205a	0.1558
Aerial Cover (cm)	2001	**17.1167a**	**28.25b**	**0.0037**
Basal Cover (cm)	2001	3.0067a	5.5658a	0.0870
# Stems/Ind Plant	2001	2.9333a	7.641a	0.0934
# Reprod Stalks/Plant	2001	1.0333a	3.5128a	**0.0512**
Density (# plants/plot)	2001	**4.0667a**	**10.7692b**	**<0.0001**
Biomass (g), 30 plants	2001	4.0332a	25.479a	0.2111
Plants Reproductive (%)	2001	**76.67a**	**100.00b**	**<0.0001**

year to year. For *B. tricholepis*, number of reproductive stalks is more likely to have a significant year by treatment interaction than growth characteristics due to the bunchgrass growth form. We would also expect *L. argenteus* to be more likely to show variation in both size and reproduction characteristics from year to year because it produces completely new aboveground growth each growing season.

Height

Figures 7, 8, and 9 show plant height of *L. argenteus* and *B. tricholepis* from 1999, 2000, and 2001, respectively. *L. dalmatica* plant height is shown from 2001. Plant height was not significantly different between treatments for either forb, *L. argenteus* and *L. dalmatica* (figures 7 and 9, respectively). *B. tricholepis* height, however, was affected by the treatments (figure 8). In all three years of study, *B. tricholepis* height was significantly greater in the partial and full treatments than in the control.

Bunchgrasses that become reproductive usually produce tall culms whereas non-reproductive bunchgrass generally do not produce such culms, as suggested by this study. In the year 2001, 96 and 98 percent of *B. tricholepis* plants in the partial and full treatments, respectively, became reproductive compared to 65 percent in the control ($p = 0.0022$, see also table 3). Lower *B. tricholepis* plant heights in the control is reflective of a lower percentage of control plants becoming reproductive.

Generally, reproductive parts of *L. argenteus* and *L. dalmatica* plants do not grow significantly taller than vegetative parts, as in *B. tricholepis*. Table 2 shows that 92 and 94 percent of *L. argenteus* plants in the partial and full treatments became reproductive compared to 69 percent in the control ($p = 0.1057$). Table 4 shows that 100 percent of *L. dalmatica* plants in the thin plus burn treatment became reproductive compared to 77 percent in the control ($p < 0.0001$). Despite these differences between treatment and control plants, height of both forbs was not statistically different.

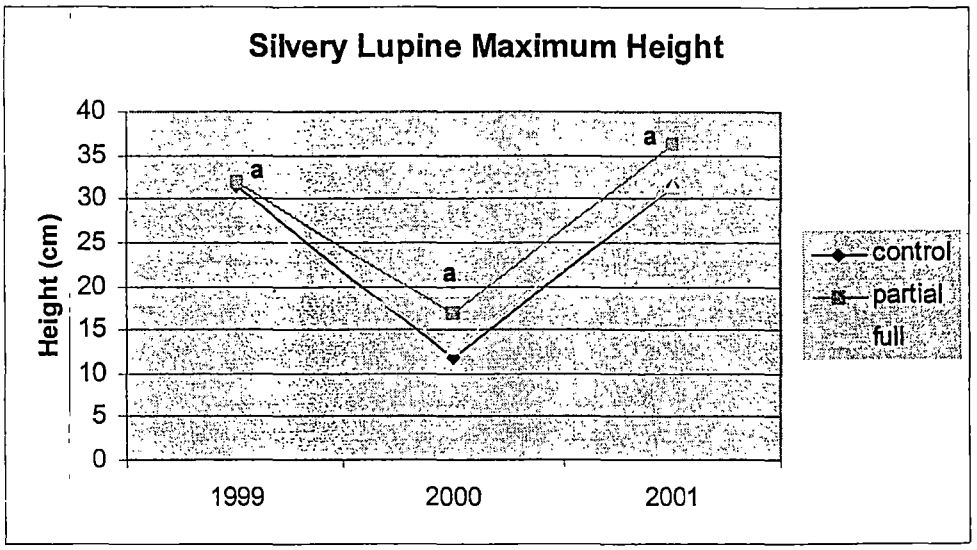


Figure 7. *Lupinus argenteus* maximum height per indicator plant in 1999, 2000, and 2001 i control, thin only partial, and thin plus burn full treatments at GPNA. ANOVA performed for each year, $\alpha = 0.10$, n = 3. Year by treatment effect was non-significant ($p = 0.6285$).

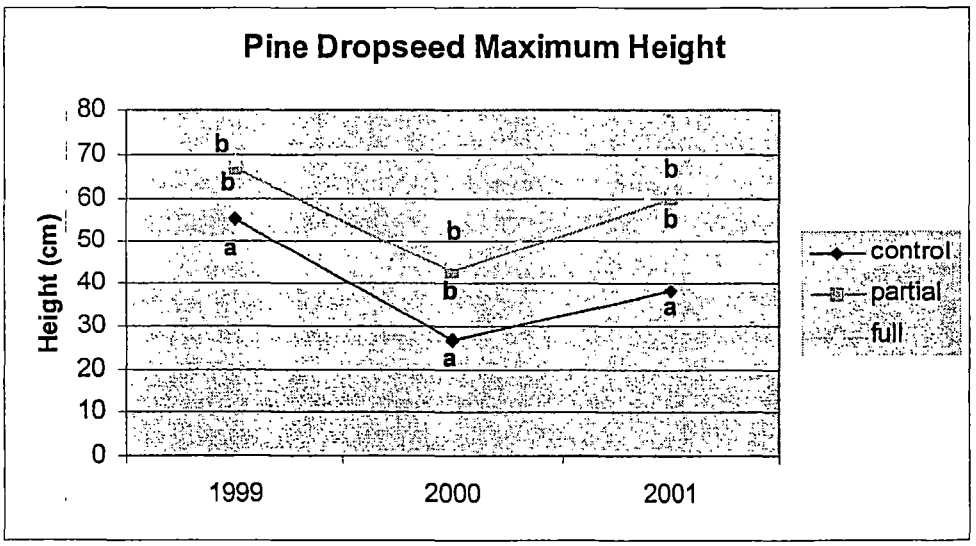


Figure 8. *Blepharoneuron tricholepis* maximum height per indicator plant in 1999, 2000, ar 2001 in control, thin only partial, and thin plus burn full treatments at GPNA. ANOVA performed for each year, $\alpha = 0.10$, n = 3. Year by treatment effect was non-significant ($p = 0.1857$).

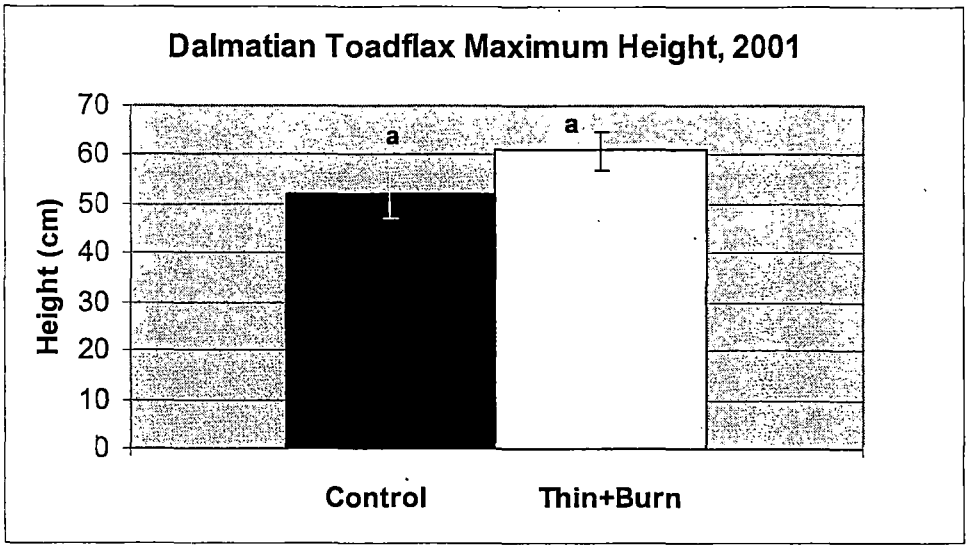


Figure 9. ANOVA for *Linaria dalmatica* maximum height per indicator plant in 2001 in control (n = 30) and thin + burn treatments (n = 39) at FUWI. $\alpha = 0.05$.

Cover

Figures 10-14 show cover results for *L. argenteus*, *B. tricholepis*, and *L. dalmatica*. Except for basal cover measurements of *L. argenteus* in 1999 and *L. dalmatica* in 2001, cover for all three species in all years was lowest in the control treatments.

In 1999, *L. argenteus* basal cover (e.g., stem diameters)was significantly greater in the full treatment compared with the partial treatment ($p = 0.0229$). In both 2000 and 2001, *L. argenteus* aerial cover was significantly greater in the partial treatment than the control, with no significant difference between full treatment cover and the other two treatments (2000, $p = 0.0612$; 2001, $p = 0.0476$).

B. tricholepis basal cover was not significantly different between treatments in 1999 ($p = 0.0948$). In 2000, *B. tricholepis* basal cover was significantly greater in the full treatment than the control ($p = 0.0462$). In 2001, basal cover of the bunchgrass was significantly greater in both the partial and full treatments compared with the control ($p = 0.0116$).

L. dalmatica aerial cover in 2001 was significantly greater in the thin plus burn treatment than the control ($p = 0.0037$), but basal cover, although nearly twice as great in treatment plants compared with control plants, showed no significant differences between treatments ($p = 0.0807$). We also compared *L. dalmatica* cover between canopy cover types between treatments (data not shown), and found that in the control treatment, aerial cover was significantly greater in the postsettlement retained canopy cover type than the grass cover type ($p = 0.0236$), showing the competitive ability of native grasses in the control treatment. When data from both treatments were lumped, *L. dalmatica* aerial and basal cover were significantly greater in the postsettlement removed canopy type than in the presettlement canopy or grass cover types (aerial cover $p = 0.0013$, basal cover $p = 0.0099$).

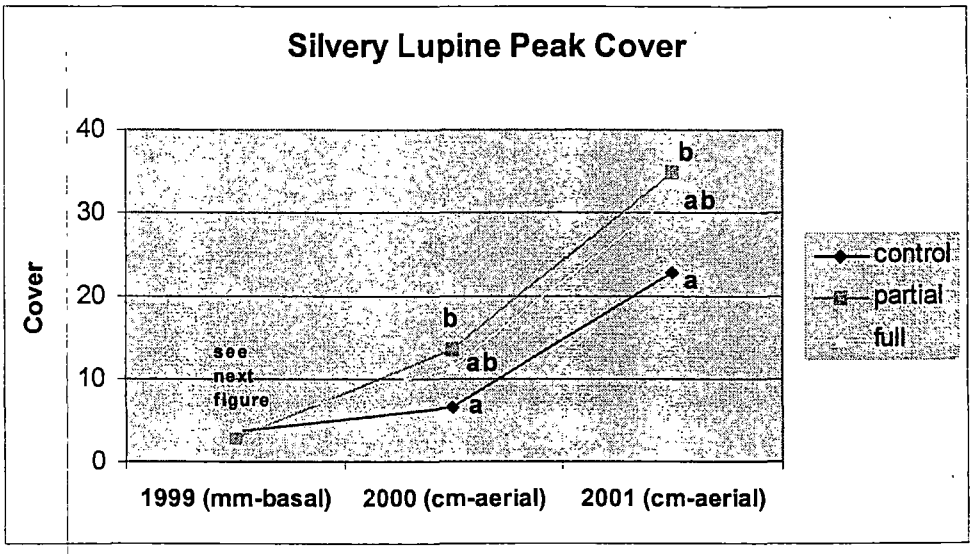


Figure 10. *Lupinus argenteus* peak cover per indicator plant in 1999, 2000, and 2001 in control, thin only partial, and thin plus burn full treatments at GPNA. ANOVA performed for each year, $\alpha = 0.10$, $n = 3$. Year by treatment effect was measured in 2000 and 2001 only because basal cover, measured in 1999, could not be directly compared to 2000 and 2001 aerial cover measurements. Year by treatment effect was non-significant ($p = 0.3224$).

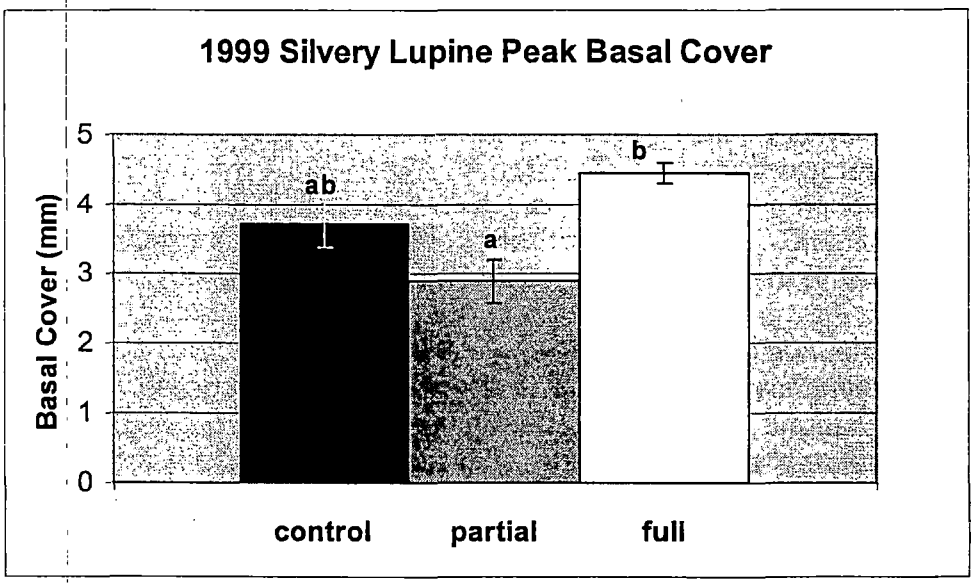


Figure 11. ANOVA for *Lupinus argenteus* peak basal cover per indicator plant in 1999 in control, thin only partial, and thin plus burn full treatments at GPNA. $\alpha = 0.10$, $n = 3$.

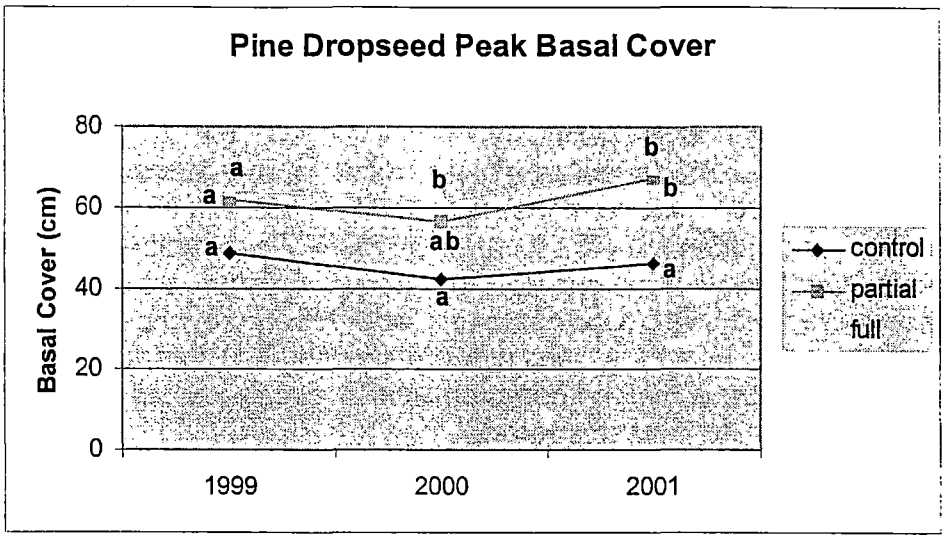


Figure 12. *Blepharoneuron tricholepis* peak basal cover per indicator plant in 1999, 2000, and 2001 in control, thin only partial, and thin plus burn full treatments at GPNA. ANOVA performed for each year, $\alpha = 0.10$, n = 3. Year by treatment effect was non-significant ($p = 0.1750$).

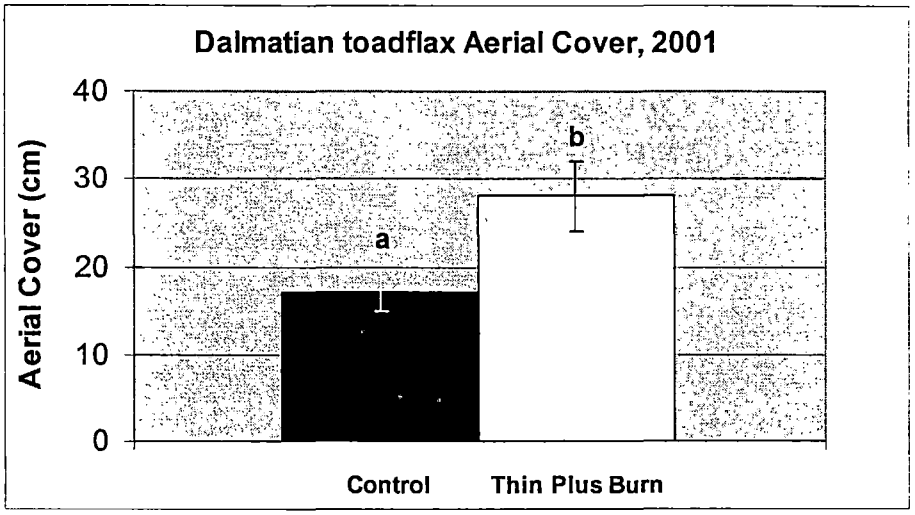


Figure 13. ANOVA for *Linaria dalmatica* peak aerial cover per indicator plant in 2001 in control (n = 30) and thin + burn treatments (n = 39) at FUWI. $\alpha = 0.05$.

This result shows that *L. dalmatica* cover is greater in heavily thinned areas in the thin plus burn treatment than any other area studied. Based on this result, restoratic practices of thinning and prescribed burning will increase *L. dalmatica* cover most severely in areas of heavy thinning.

Cover, a measure of the area beneath the canopy (aerial) or base (basal) of a given species, can be used to measure the relative amount of nutrients or other resources a plant commands (Barbour et al. 1999). Cover was generally lowest in th control treatment for all three species, therefore, the control treatment is likely a stressed environment where nutrients and other resources are lower than those of the treatment areas. Cover, as well as other growth and reproduction variables measured in this study, may be compromised for simple plant survival in the control treatment for all three of these species.

Number of Stems (*Linaria dalmatica* only)

The number of stems per *L. dalmatica* indicator plant was counted to assess plant vigor because large plants often have a prolific number of stems, which may n be reflected in height or cover measurements. Due to great variation, stem number was not significantly different between treatments ($p = 0.0934$, see also figure 15). However, *L. dalmatica* plants in the thin plus burn treatment bore two and one-half times the number of stems than control plants.

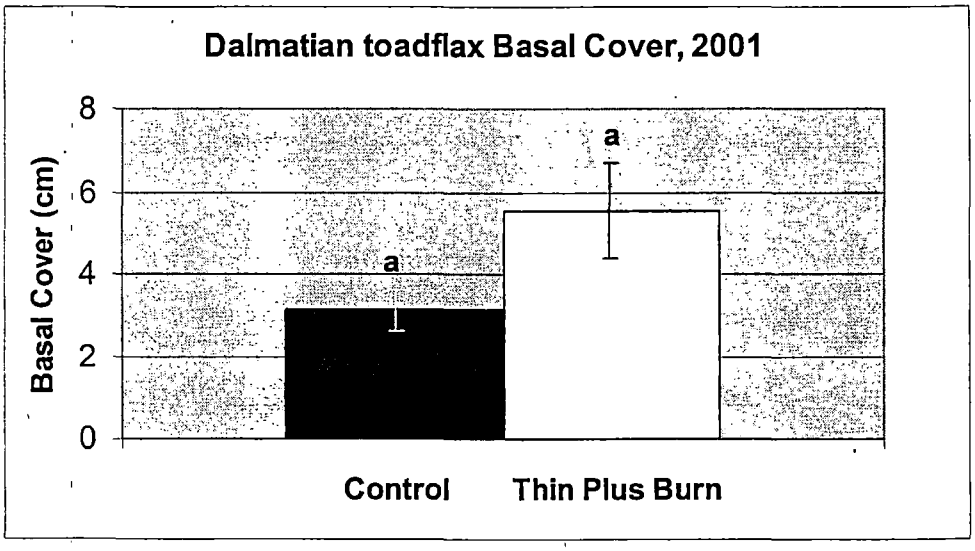


Figure 14. ANOVA for *Linaria dalmatica* peak basal cover per indicator plant in 2001 in control (n = 30) and thin + burn treatments (n = 39) at FUWI. $\alpha = 0.05$.

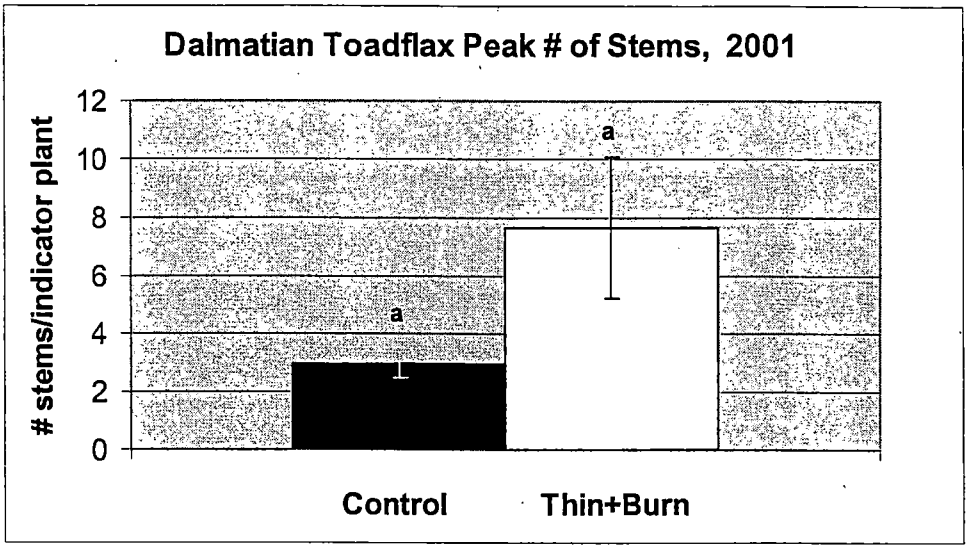


Figure 15. ANOVA for *Linaria dalmatica* number of stems per indicator plant in 2001 in control (n = 30) and thin + burn treatments (n = 39) at FUWI. $\alpha = 0.05$.

Reproduction

Figures 16-19 show the peak number of reproductive stalks per *L. argenteus*, *B. tricholepis*, and *L. dalmatica* indicator plant. The lowest number of reproductive stalks per *L. argenteus* plant was produced in the control treatment in all three years. Differences were not significant between treatments in 1999 ($p = 0.7324$) and 2000 ($p = 0.1043$). In 2001, partial treatment plants bore significantly more reproductive stalks than control plants ($p = 0.0602$). Note how few reproductive stalks were produced during the drought year, 2000. Even in the partial treatment in 2000, where *L. argenteus* plants bore the most reproductive stalks, plants averaged less than one reproductive stalk compared with 21 reproductive stalks per plant in the year 2001.

Number of reproductive stalks per *B. tricholepis* plant was lowest in the control in all three years. Significant differences were not detected in 1999 ($p = 0.1433$). In 2000, plants in the treated area bore significantly more reproductive stalks than control plants ($p = 0.0141$). In 2001, differences were significant between the full and control treatments only ($p = 0.0188$). A connection between fire and *B. tricholepis* reproduction is possible. Reproductive stalks in the thin plus burn treatment continued to increase from 1999, one year after fire, to 2001, despite the drought. Meanwhile, reproductive stalks declined in both the partial and the control treatments, where prescribed burning was not implemented. Grasses can respond to fire by suppressing reproduction immediately after fire, then increasing dramatically in subsequent growing seasons (White et al. 1991). Alternatively, *B. tricholepis* may be stressed after fire, and one stress response to drought by some plants is to prolifically reproduce. *B. tricholepis* in the full treatment may be responding to the 1998 prescribed burn or to the drought or too a combination of abiotic factors.

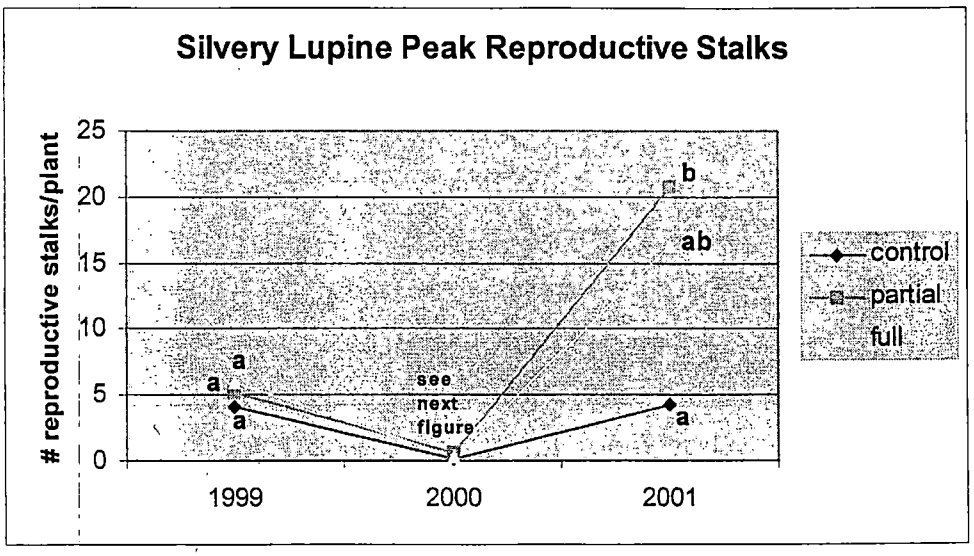


Figure 16. *Lupinus argenteus* peak number of reproductive stalks per indicator plant in 199 2000, and 2001 in control, thin only partial, and thin plus burn full treatments at GPNA. ANOVA performed for each year, α = 0.10, n = 3. Year by treatment effect was **significant** = 0.0108).

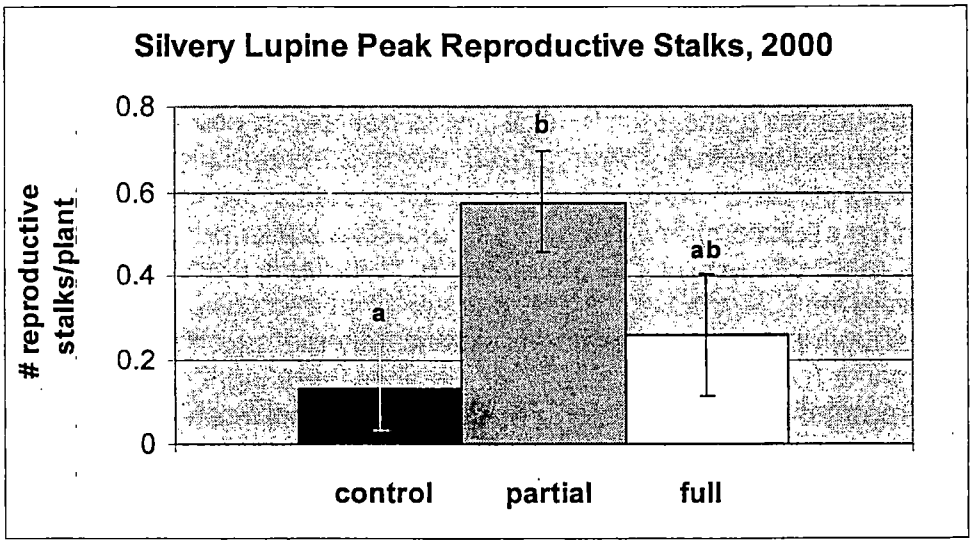


Figure 17. ANOVA for *Lupinus argenteus* peak number of reproductive stalks per indicator plant in 2000 in control, thin only partial, and thin plus burn full treatments at GPNA. α = 0. n = 3.

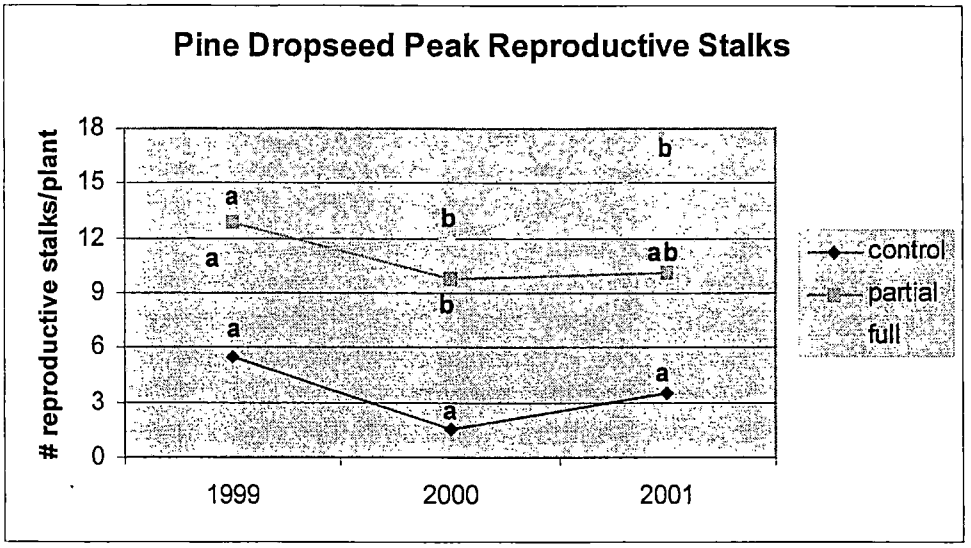


Figure 18. *Blepharoneuron tricholepis* peak number of reproductive stalks per indicator plant in 1999, 2000, and 2001 in control, thin only partial, and thin plus burn full treatments at GPNA. ANOVA performed for each year, $\alpha = 0.10$, $n = 3$. Year by treatment effect was **significant** ($p = 0.0672$).

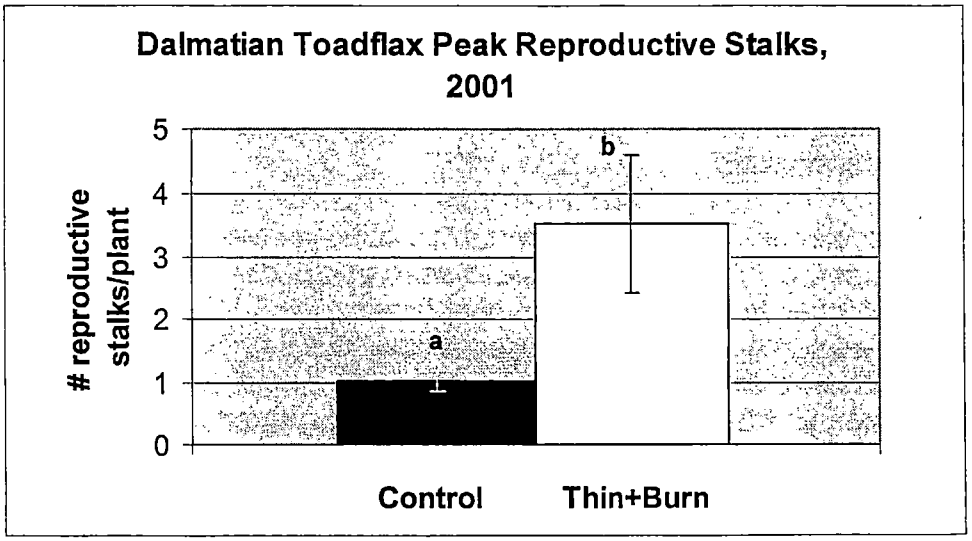


Figure 19. ANOVA for *Linaria dalmatica* peak number of reproductive stalks per indicator plant in 2001 in control ($n = 30$) and thin + burn treatments ($n = 39$) at FUWI. $\alpha = 0.05$.

Number of reproductive stalks per *L. dalmatica* plant in 2001 did not differ significantly between treatments ($p = 0.0512$). However, in the thin plus burn treatment, *L. dalmatica* plants bore 3.5 reproductive stalks compared to only one reproductive stalk per plant in the control treatment. Greater reproduction of noxious weeds at restoration sites may pose grave danger to potential success of remediation. However, if increased reproduction at restoration sites also occurs in native plants, such as *L. argenteus* and *B. tricholepis*, then competition for released resources will hopefully keep noxious weeds, such as *L. dalmatica*, at bay.

Figures 20, 21, and 22 show mean number of reproductive stalks per *L. argenteus*, *B. tricholepis*, and *L. dalmatica* plant in each treatment during the entire 2001 reproductive period. Repeated measures analysis of variance (Ott 1993) was used to test the hypothesis that the mean number of reproductive stalks per plant is different between treatments over time. The date by treatment interaction was significant for all three species (*L. argenteus*, $p < 0.0001$; *B. tricholepis*, $p = 0.0002$; *L. dalmatica*, $p < 0.0001$). This result means that over the duration of the 2001 growing season, average number of reproductive stalks per *L. argenteus*, *B. tricholepis*, and *L. dalmatica* plant was significantly different between treatments.

Early in the 2001 reproductive period of *L. argenteus*, the fewest reproductive stalks per plant occurred in the partial treatment. Then, partial treatment plants produced the greatest reproductive output during the peak reproductive period from July 25 to September 7, 2001. Full treatment plants also had high reproductive outp during the peak reproductive period. Full treatment plants remained reproductive longer than plants in partial or control treatments. Control plants had the greatest reproductive output early in the period, then the lowest reproductive output during th remainder of the reproductive period, indicating a possible stress response throughout the growing season (Bazzaz et al. 1987). Plants in all three treatments followed approximately the same pattern, with peak 2001 reproduction in August during monsoon rains.

Throughout the 2001 *B. tricholepis* reproductive period, full treatment plants consistently had the greatest number of reproductive stalks, partial treatment plants had fewer, and control plants had the fewest reproductive stalks possibly indicating limited resources in the control treatment (Bazzaz et al. 1987). Peak reproduction o the warm season bunchgrass occurred around October 10, 2001 when monsoon rains had ceased and cool autumn temperatures began. *B. tricholepis* plants in all three treatments followed approximately the same pattern throughout the reproductive period.

Throughout the 2001 *L. dalmatica* reproductive period, thin plus burn treatment plants consistently had the greatest number of reproductive stalks compared with control treatment plants. Peak reproduction of the noxious weed occurred on June 26, 2001 in the thin plus burn treatment, and on July 10, 2001 in the control. *L. dalmatica* plants in both treatments followed approximately the same pattern throughout the reproductive period.

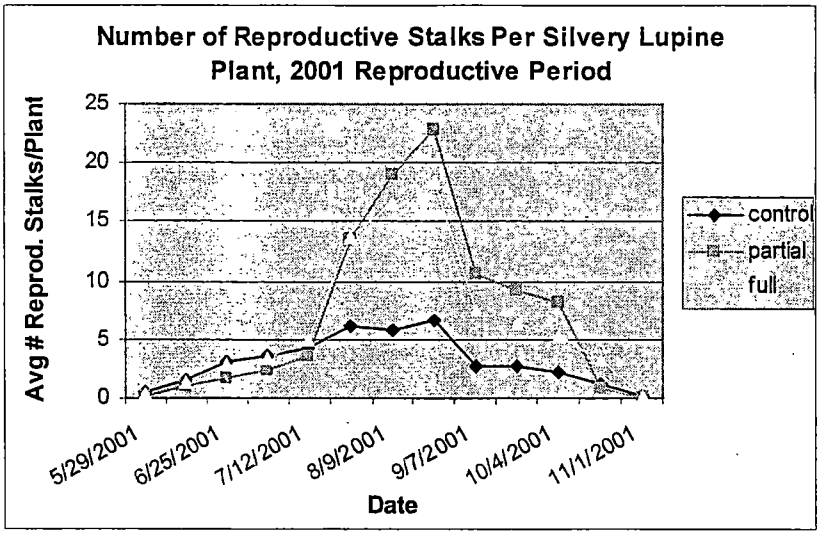


Figure 20. Average number of reproductive stalks per indicator plant at each data collection date of *Lupinus argenteus* at the GPNA study site in 2001. Repeated measures analysis showed a **significant** date by treatment effect ($p < 0.0001$).

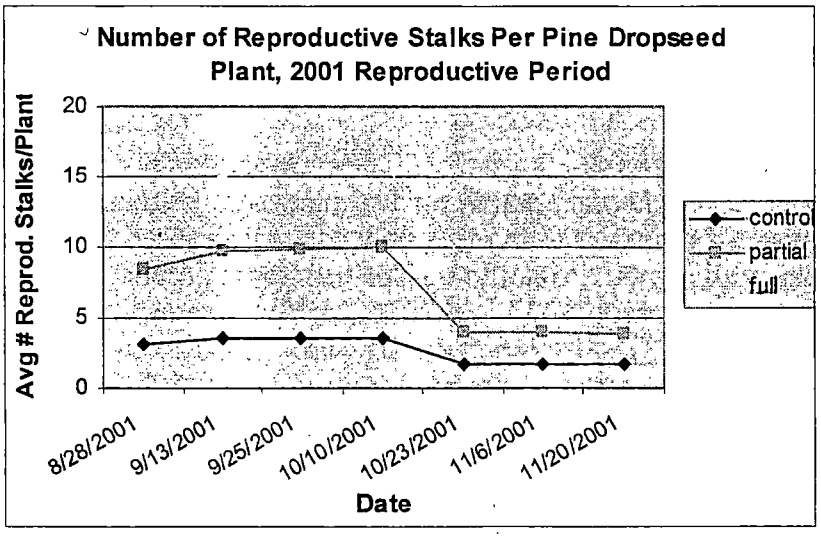


Figure 21. Average number of reproductive stalks per indicator plant at each data collection date of *Blepharoneuron tricholepis* at the GPNA study site in 2001. Repeated measures analysis showed a **significant** date by treatment effect ($p < 0.0002$).

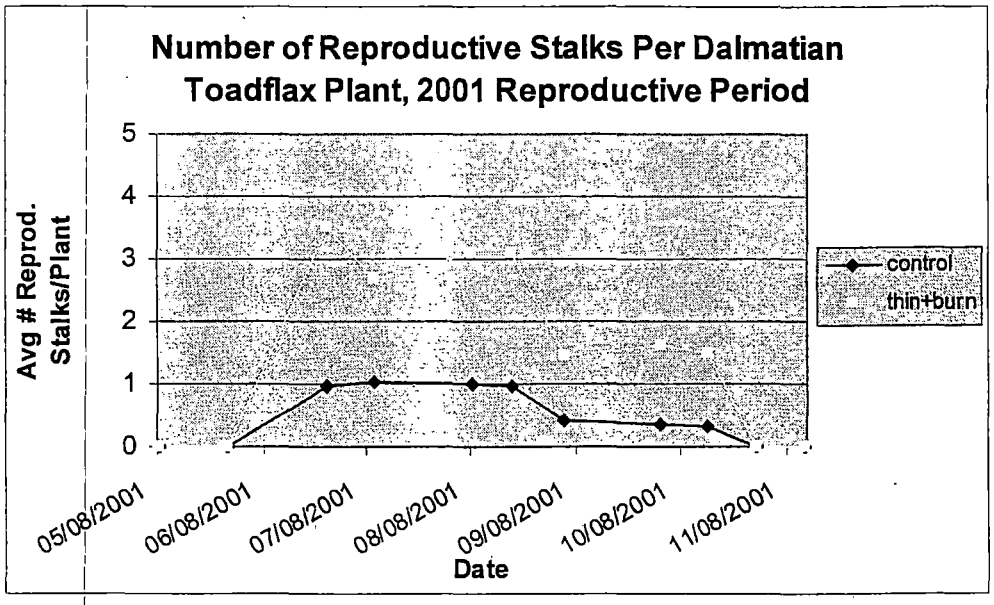


Figure 22. Average number of reproductive stalks per indicator plant at each data collectior date of *Linaria dalmatica* at the GPNA study site in 2001. Repeated measures analysis showed a **significant** date by treatment effect ($p < 0.0001$).

Density

Shown in figures 23, 24, and 25, local plant density of *L. argenteus*, *B. tricholepis*, and *L. dalmatica* plants on $1m^2$ plots was generally greater in the thin pl burn treatments compared to the thin only or controls in all years. *L. argenteus* density was significantly greater in the full treatment compared to the partial and control treatments in both 1999 and 2000. In 1999, one year after the last prescribe fire occurred in 1998, *L. argenteus* density was 11 plants per plot compared to only plants per plot in the partial and control treatments. In 2000, *L. argenteus* density w 5 plants per plot compared to 2.5 and 1.8 plants per plot in the partial and control treatments, respectively. Then, in 2001, although differences were not statistically significant, density was nearly twice as great in the full treatment compared with the control and partial treatments, where burning has not occurred since 1876 (Dieteric 1980). It is interesting to note how great *L. argenteus* density was in the full treatme in 1999, one year after prescribed fire. *L. argenteus* vegetative sprouting are knowr to be stimulated by fire (Flinn and Wein 1977), and seed germination of leguminous species is stimulated by heat (Shea et al. 1979, Cavanagh 1980, Bradstock and Au 1995). Our results support such findings for *L. argenteus* plants.

In all three years, *B. tricholepis* plant densities were not significantly differen between treatments, but densities were consistently greater in the full treatment tha the partial and control treatments. *B. tricholepis*, like *L. argenteus*, may also be stimulated by fire.

In 2001, *L. dalmatica* plant density was significantly greater in the thin plus burn treatment than the control. These data show that noxious weed densities may

increase with restoration practices of thinning and prescribed burning, and indicate a need for close monitoring and possible remediation of noxious weeds at restoration sites. We also compared *L. dalmatica* density between canopy cover types with treatment data lumped (data not shown), and found that density was significantly greater in the postsettlement removed canopy cover type than the postsettlement retained canopy and grass cover types ($p = 0.0273$). This result shows that *L. dalmatica* plant density is greater in heavily thinned areas in the thin plus burn treatment than lightly thinned, unthinned, and grassy areas. Based on this result, restoration practices of thinning and prescribed burning will increase *L. dalmatica* density most severely in areas of heavy thinning.

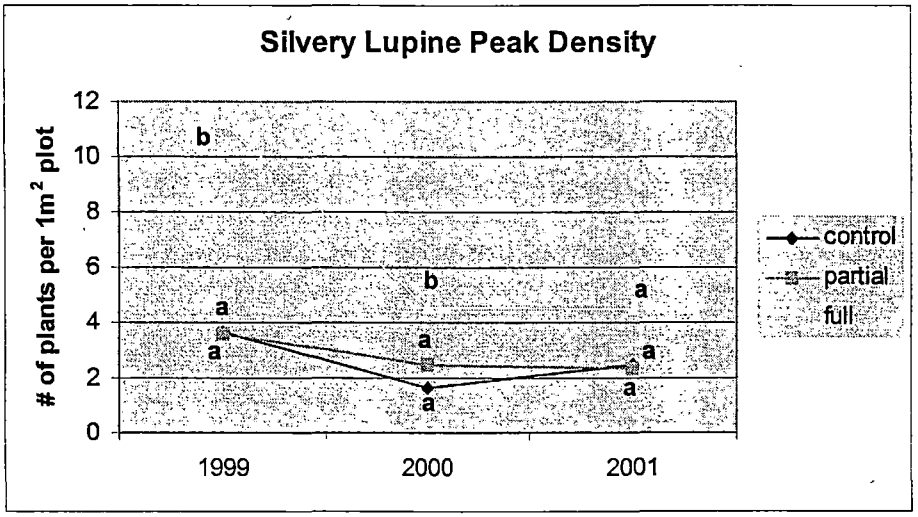


Figure 23. *Lupinus argenteus* peak density per $1m^2$ plot in 1999, 2000, and 2001 in control, thin only partial, and thin plus burn full treatments at GPNA. ANOVA performed for each year, $\alpha = 0.10$, $n = 3$. Year by treatment effect was **significant** ($p < 0.0001$).

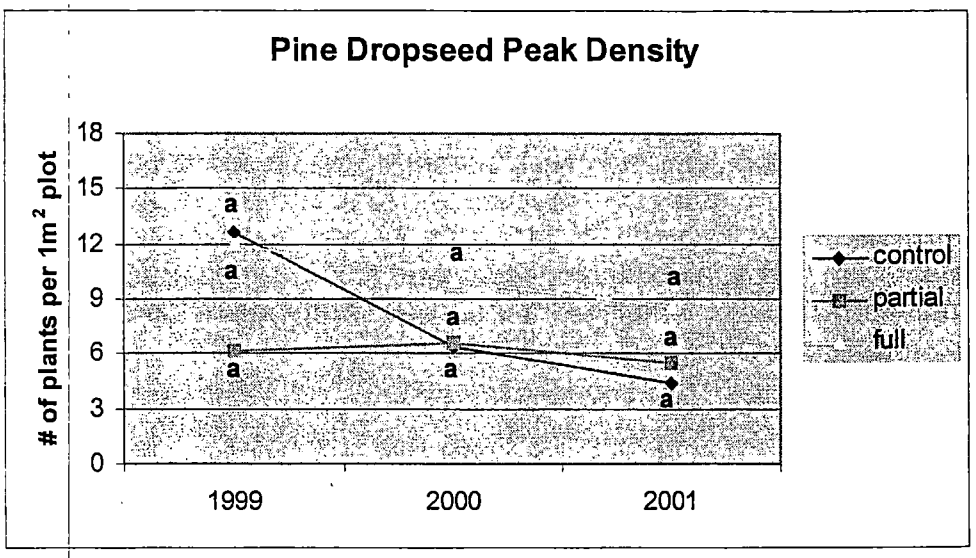


Figure 24. *Blepharoneuron tricholepis* peak density per $1m^2$ plot in 1999, 2000, and 2001 i control, thin only partial, and thin plus burn full treatments at GPNA. ANOVA performed for each year, $\alpha = 0.10$, n = 3. Year by treatment effect was non-significant (p = 0.4471).

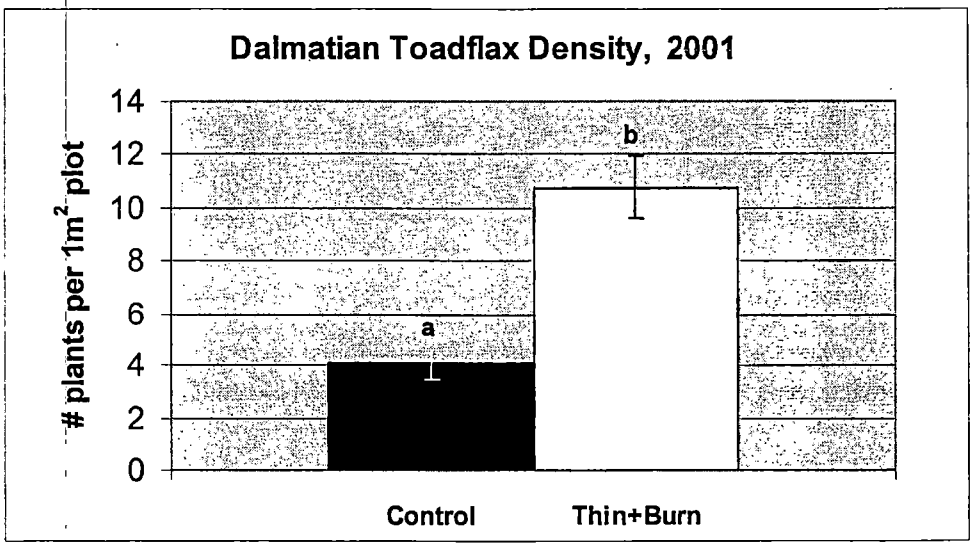


Figure 25. ANOVA for *Linaria dalmatica* peak density per $1m^2$ plot in 2001 in control (n = 3 and thin + burn treatments (n = 39) at FUWI. $\alpha = 0.05$.

Biomass

L. argenteus, *B. tricholepis*, and *L. dalmatica* biomass was collected only in 2001. Mean aboveground biomass per *L. argenteus* plant was 3.0 g in the control, 13.3 g in the partial treatment, and 11.6 g in the full treatment. Biomass differences were statistically significant between partial and control treatments only ($p = 0.0496$) (figure 26).

Mean aboveground biomass per *B. tricholepis* plant was 1.6 g in the control, 4.0 g in the partial treatment, and 4.3 g in the full treatment. Biomass was significantly greater in the partial and full treatments compared with the control ($p = 0.0191$) (figure 27).

Mean aboveground biomass per *L. dalmatica* plant was 4.0 g in the control and 10.8 g in the thin plus burn treatment (figure 28). Despite this considerable difference in biomass per plant, differences were not statistically significant ($p = 0.2111$) and non-parametric statistics are recommended in future analyses. We also compared *L. dalmatica* biomass between canopy cover types with treatment data lumped (data not shown), and found that biomass was significantly greater in the postsettlement removed canopy cover type than all three other cover types ($p = 0.0066$). This result shows that *L. dalmatica* plant biomass is greater in heavily thinned areas in the thin plus burn treatment than any other area studied. Based on this result, restoration practices of thinning and prescribed burning will increase *L. dalmatica* biomass most severely in areas of heavy thinning.

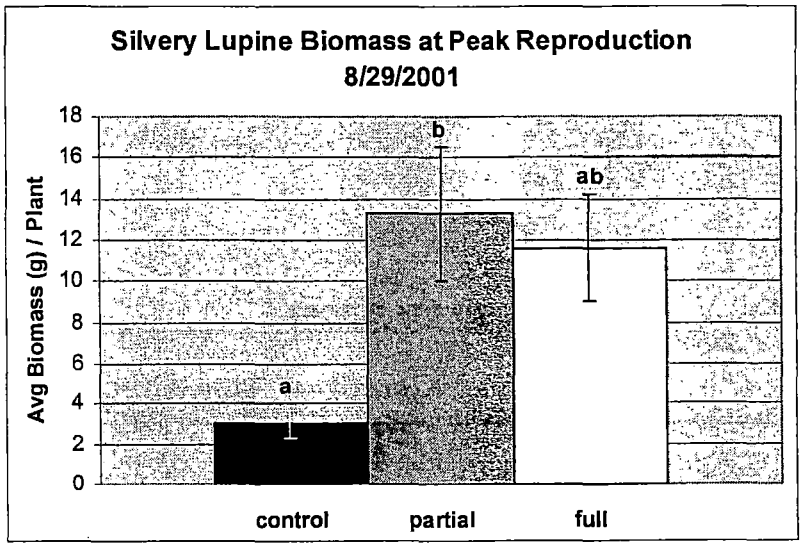


Figure 26. ANOVA for *Lupinus argenteus* peak biomass per indicator plant in 2001 in control, thin only partial, and thin plus burn full treatments at GPNA. $\alpha = 0.10$, $n = 3$.

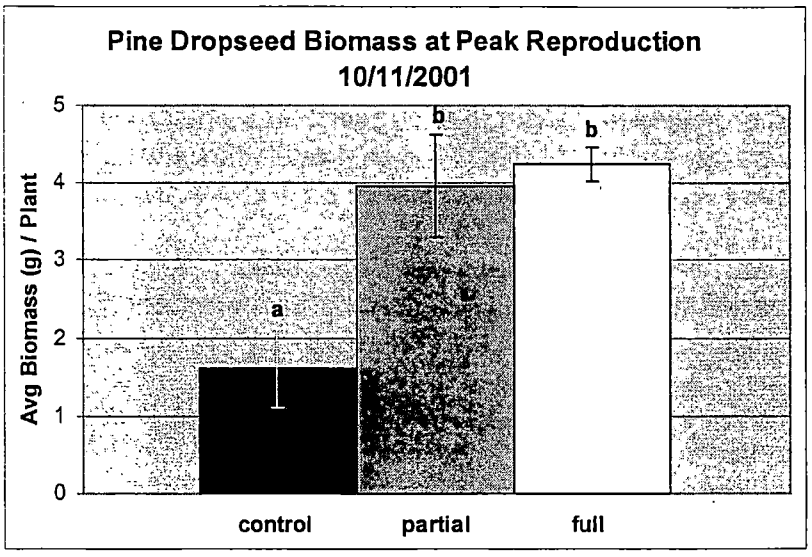


Figure 27. ANOVA for *Blepharoneuron tricholepis* peak biomass per indicator plant in 2001 control, thin only partial, and thin plus burn full treatments at GPNA. $\alpha = 0.10$, $n = 3$.

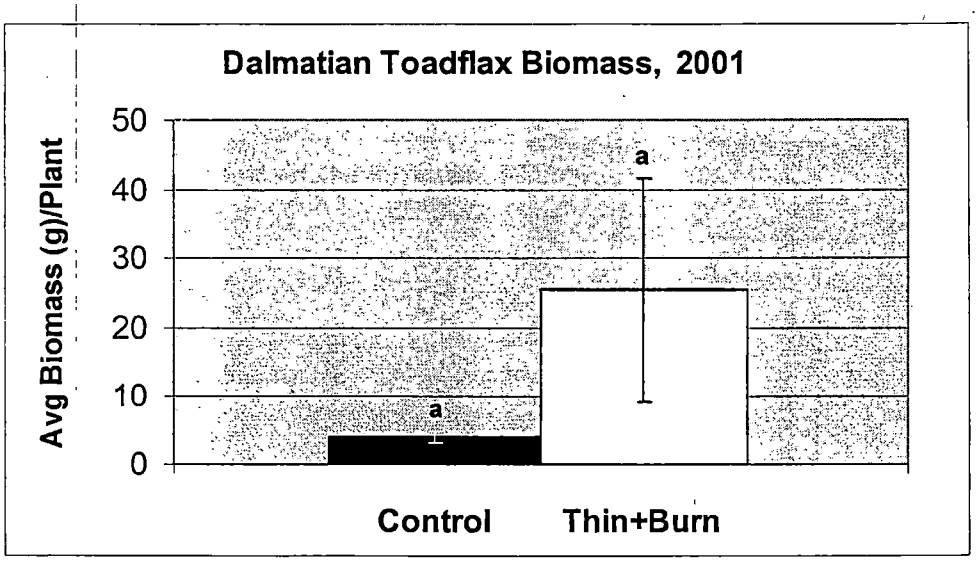


Figure 28. ANOVA for *Linaria dalmatica* peak biomass per indicator plant in 2001 in control ($n = 14$) and thin + burn treatments ($n = 16$) at FUWI. $\alpha = 0.05$.

ENVIRONMENTAL VARIABLES

Tables 5 and 6, and figures 29-34 show daily PAR and forest floor depth measurements on *Lupinus argenteus* and *Blepharoneuron tricholepis* 1m^2 plots.

Light intensity (PAR) measurements on *L. argenteus* 1m^2 plots, shown in table 5 and figures 29 and 30, were greatest in the partial and full treatments and lowest in the control at morning (8-10 am), midday (11 am-1 pm), and afternoon (3-5 pm). Afternoon was the only time period, however, that PAR was significantly greater in the treated areas than the control (figure 29). Shown in figure 30, morning, midday, and afternoon PAR measurements were averaged, resulting in average daily PAR of 656 µmols/m^2/sec in the control, 1028 µmols/m^2/sec in the partial treatment, and 1072 µmols/m^2/sec in the full treatment. Significantly more sunlight (average daily PAR) penetrated the tree canopy throughout the day in the partial and full treatments than in the control ($p = 0.0007$).

Table 5. *Lupinus argenteus* ANOVA summary comparing PAR and forest floor depths in the control, partial and full treatments at GPNA in 2001. Measurements were collected on 1m^2 plots. Different lower case letters after treatment values indicate that means are significantly different. $\alpha = 0.10$, $n = 3$, approximately 50 plots.

Lupinus argenteus	**Year**	**Control**	**Partial**	**Full**	**p-value**
PAR 8-10am (µmols/m^2/sec)	2001	437.65a	743.60a	831.20a	0.4817
PAR 11am-1pm (µmols/m^2/sec)	2001	1185.59a	1359.82a	1654.59a	0.1205
PAR 3-5pm (µmols/m^2/sec)	2001	**344.67a**	**938.01b**	730.59ab	0.102
Avg Daily PAR (µmols/m^2/sec)	2001	**655.97a**	**1028.08b**	**1072.13b**	0.0007
Litter depth (in)	2001	**1.7178a**	1.4503ab	**1.0101b**	0.0468
Fermentation + Humus (in)	2001	**0.7178a**	**0.5225b**	**0.2670c**	0.0017

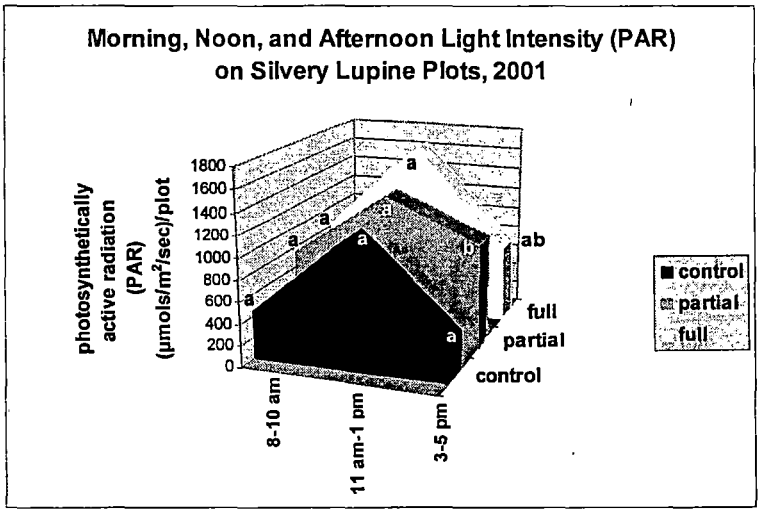


Figure 29. ANOVA comparison between treatments of light intensity (PAR) on *Lupinus argenteus* plots at morning (8-10 am, June 28, 2001), midday (11 am–1 pm, June 27, 2001) and afternoon (3-5 pm, June 28, 2001). Different lower case letters at each time period indicate that means are significantly different. $\alpha = 0.10$, $n = 3$.

As expected, forest floor depths were lowest in the thinned plus burned full treatment. Litter layer depth on *L. argenteus* plots, shown in table 5 and figure 31, was significantly greater in the control (1.72 in) than the full treatment (1.01 in) with no significant difference in litter depth between the partial (1.45 in) and the other two treatments ($p = 0.0468$). Humus + fermentation layer depth was significantly greater in the control (0.72 in) than the partial (0.52 in) and full (0.27 in) treatments, and further, significantly greater in the partial than the full treatment ($p = 0.0017$).

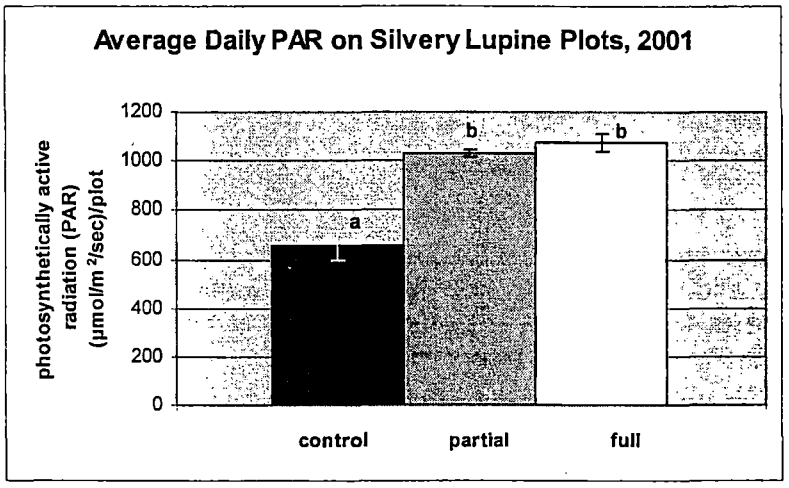


Figure 30. Average daily light intensity (PAR) comparison between treatments on *Lupinus argenteus* plots using ANOVA. Different lower case letters above standard error bars indicate that means are significantly different. $\alpha = 0.10$, $n = 3$.

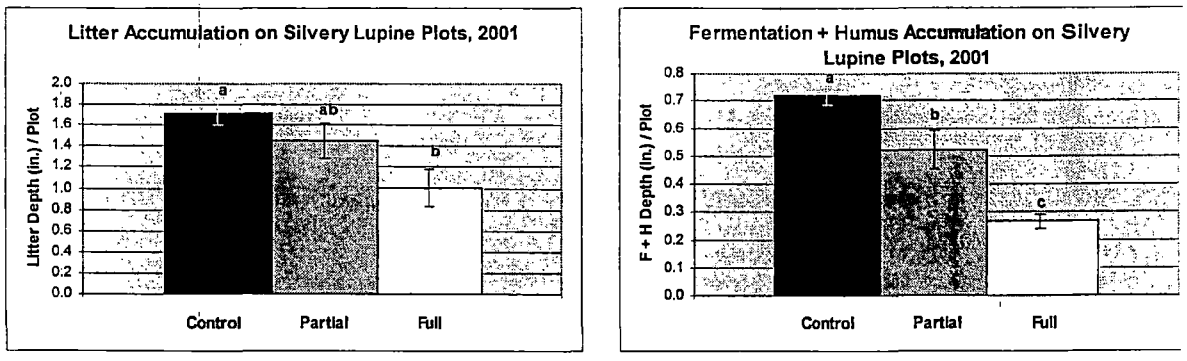


Figure 31. Comparison of litter accumulation and fermentation + humus accumulation between treatments on *Lupinus argenteus* plots using ANOVA. Different lower case letters above standard error bars indicate that means are significantly different. $\alpha = 0.10$, $n = 3$.

Light intensity (PAR) measurements on *B. tricholepis* 1m^2 plots, shown in table 6 and figures 32 and 33, were greatest in the partial and full treatments and lowest in the control at morning (8-10 am), midday (11 am-1 pm), and afternoon (3-5 pm). Afternoon was the only time period, however, that PAR was significantly greater in the full treatment than the control with no significant difference between the partial and the other two treatments (figure 32). Shown in figure 33, morning, midday, and afternoon PAR measurements were averaged, resulting in average daily PAR of 594 µmols/m^2/sec in the control, 1030 µmols/m^2/sec in the partial, and 1025 µmols/m^2/sec in the full treatment. Significantly more sunlight (average daily PAR) penetrated the tree canopy throughout the day in the partial and full treatments than in the control ($p = 0.0041$).

As expected, forest floor depths were lowest in the thinned plus burned full treatment. Litter layer depth on *B. tricholepis* plots, shown in table 6 and figure 34, was significantly greater in the control (0.2337 in) than both the partial (0.1201 in) and full treatments (0.0800b in) ($p = 0.0078$). There were no statistically significant differences detected in the fermentation + humus layer between treatments ($p = 0.2470$), although depths were lowest in the full treatment.

At GPNA, dense forest stands in the control treatment are likely responsible for greater forest floor depths and lower light intensities on both *L. argenteus* and *B. tricholepis* plots compared to the partial and full treatments where postsettlement trees were thinned. Prescribed fire in the full treatment is probably responsible for lower forest floor depths compared to the partial treatment where thinning only occurred. Additionally, total forest floor depths were greater beneath *L. argenteus* plants (1.90 in.) compared with shallower forest floor depths beneath *B. tricholepis* plants (0.57 in.) ($n = 9$, $p < 0.0001$). This indicates that *L. argenteus* may be able to grow and survive in deeper forest floor depth conditions than *B. tricholepis* plants. Historically in northern Arizona, bunchgrasses such as *B. tricholepis*, dominated the herbaceous understory, whereas forbs such as *L. argenteus*, were considered "weedy" and increased with ponderosa pine seedling density (Arnold 1950). Our findings of greater forest floor depths beneath *L. argenteus* plants compared to shallower forest floor depths beneath *B. tricholepis* plants support that forb survival is favored over bunchgrass survival with increased tree densities.

Table 6. *Blepharoneuron tricholepis* ANOVA summary comparing PAR and forest floor depths in the control, partial and full treatments at GPNA in 2001. Measurements were collected on 1m^2 plots. Different lower case letters after treatment values indicate that means are significantly different. $\alpha = 0.10$, $n = 3$, approximately 50 plots.

Blepharoneuron tricholepis	**Year**	**Control**	**Partial**	**Full**	**p-value**
PAR 8-10am (µmols/m^2/sec)	2001	220.73a	496.83a	568.39a	0.1479
PAR 11am-1pm (µmols/m^2/sec)	2001	1367.00a	1829.39a	1700.34a	0.1048
PAR 3-5pm (µmols/m^2/sec)	2001	**193.50a**	764.63ab	**806.27b**	0.0630
Avg Daily PAR (µmols/m^2/sec)	2001	**593.74a**	**1030.28b**	**1025.00b**	0.0041
Litter depth (in)	2001	**0.2337a**	**0.1201b**	**0.0800b**	0.0078
Fermentation + Humus (in)	2001	0.4658a	0.4818a	0.3296a	0.2470

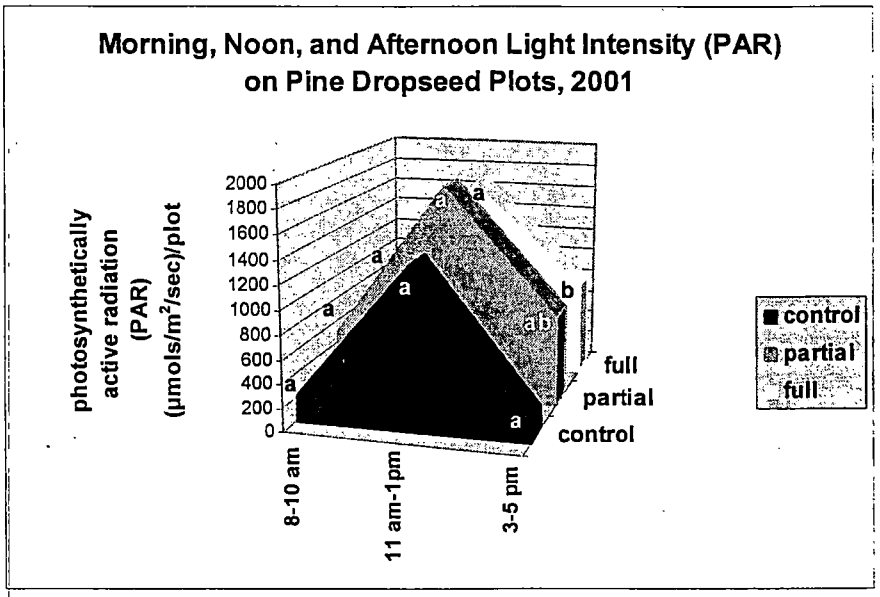


Figure 32. ANOVA comparison between treatments of light intensity (PAR) on *Blepharoneuron tricholepis* plots at morning (8-10 am, June 29, 2001), midday (11 am–1 pr June 28, 2001), and afternoon (3-5 pm, July 16, 2001). Different lower case letters at each time period indicate that means are significantly different. $\alpha = 0.10$, $n = 3$.

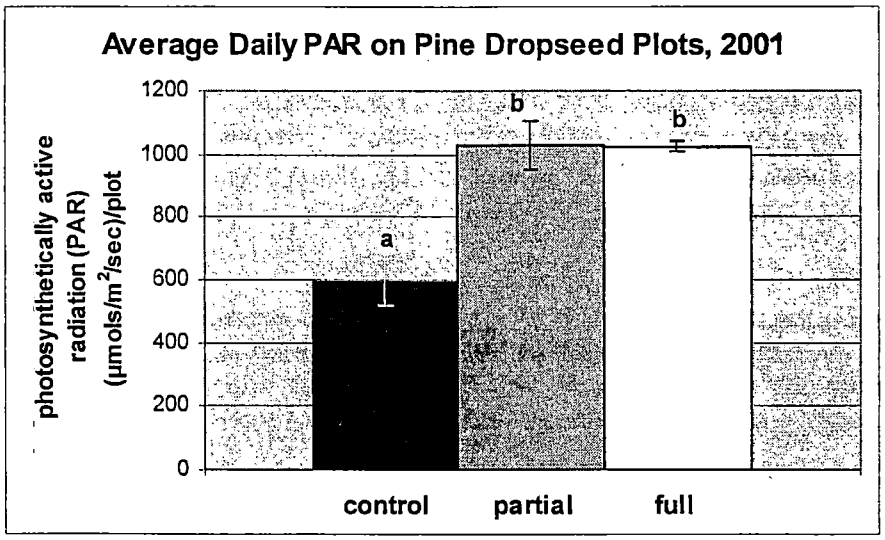


Figure 33. Average daily light intensity (PAR) comparison between treatments on *Blepharoneuron tricholepis* plots using ANOVA. Different lower case letters above standarc error bars indicate that means are significantly different. $\alpha = 0.10$, $n = 3$.

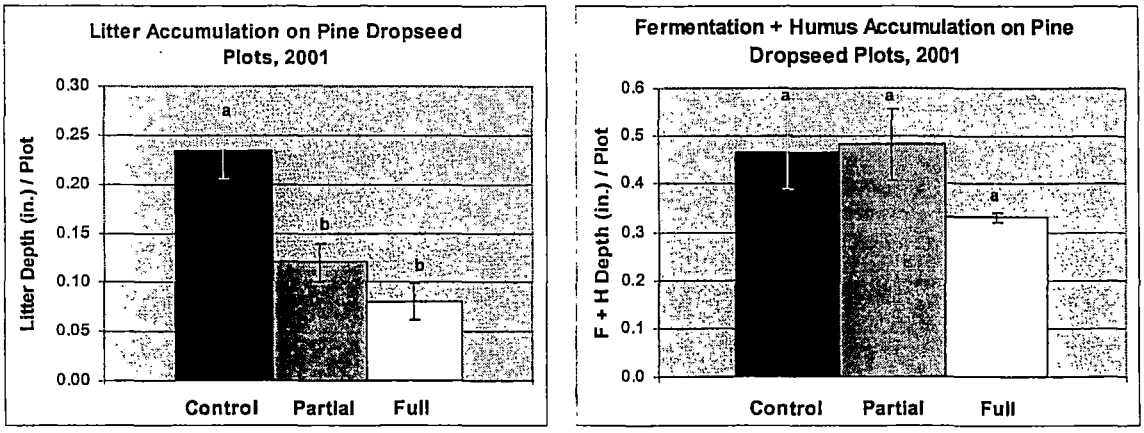


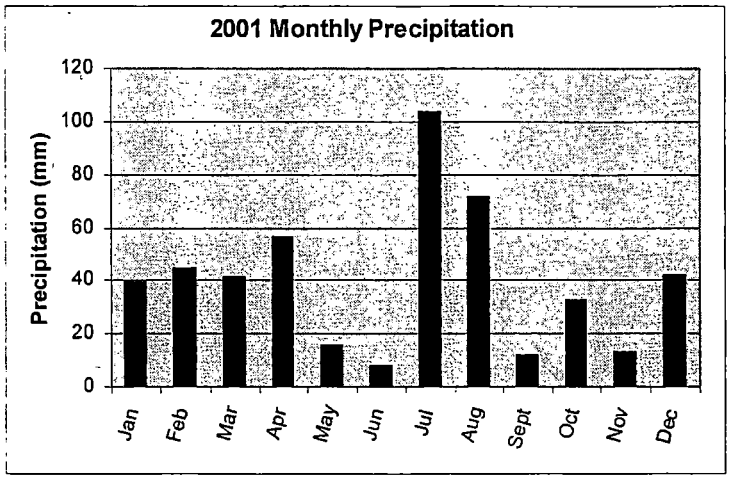
Figure 34. Comparison of litter accumulation and fermentation + humus accumulation between treatments on *Blepharoneuron tricholepis* plots using ANOVA. Different lower case letters above standard error bars indicate that means are significantly different. $\alpha = 0.10$, $n = 3$.

Mean annual temperature in 2001 at GPNA was 6.63 °C. Total annual precipitation in 2001 was 48 cm. Figure 35 shows total monthly precipitation during the year 2001, and volumetric water content (VWC) of soil during the 2001 growing season both weekly and in its peak week. Maximum precipitation occurred in July and August during the monsoon season, co-occurring with peak number of reproductive *L. argenteus* stalks per plant and just prior to the onset of *B. tricholepis* reproduction.

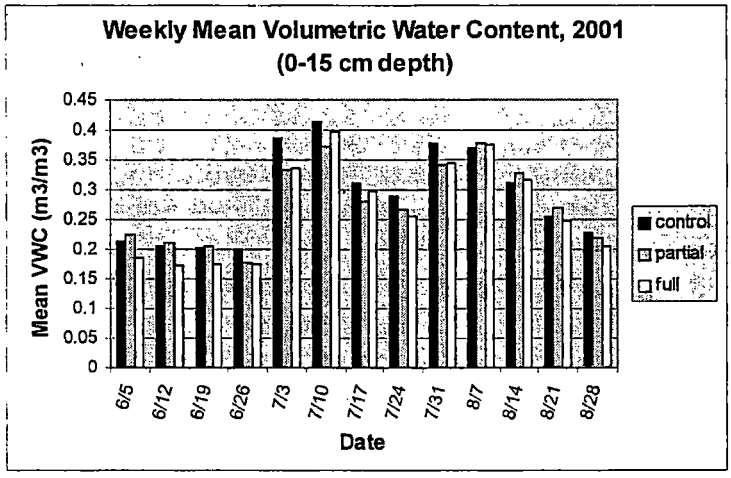
Average VWC of soil was measured beginning on June 4, when establishment of the sensors was complete, to December 31, 2001. Soil VWC was 0.252 m^3/m^3 in the control, 0.239 m^3/m^3 in the partial treatment, and 0.222 m^3/m^3 in the full treatment ($p = 0.4050$). Peak VWC occurred the week of July 11 in both the control (0.414 m^3/m^3) and full (0.398 m^3/m^3) treatments, and the week of August 8, 2001 in the partial treatment (0.377 m^3/m^3) ($p = 0.3650$). Minimum weekly VWC occurred in all three treatments just before summer monsoon rains began and was not significantly different between treatments ($p = 0.3588$). Minimum weekly VWC occurred in the full treatment on June 13 (0.173) and in the control (0.201) and partial (0.177) treatments on June 27. Although VWC was similar in all three treatments, dense forest tree structure in the control treatment may create greater plant competition for soil moisture than occurs in the thinned only or thinned plus burned treatments (Feeney et al. 1998, Stone et al. 1999), contributing to differences we found in plant growth and reproduction between treatments.

Average soil temperature from June 4 to December 31, 2001 was 10.8 °C in the control, 10.6 °C in the partial, and 12.1 °C in the full treatment. Differences were not statistically significant ($p = 0.1685$).

a)



b)



c)

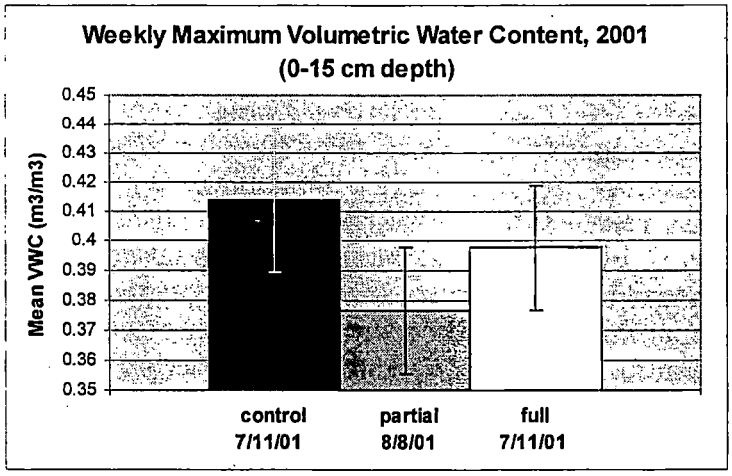


Figure 35. a) Monthly 2001 precipitation, in one location at study site, b) weekly mean volumetric water content (VWC) of soil, and c) maximum weekly volumetric water content soil. ANOVA shows VWC is not significantly different between treatments. $\alpha = 0.10$, $n = 6$ (control), $n = 8$ (partial and full).

Table 7 and figures 36 and 37 show daily PAR and forest floor depth measurements on *Linaria dalmatica* 1m^2 plots. Light intensities (PAR) on *L. dalmatica* 1m^2 plots were similar in the control and thin plus burn treatments. There were no significant differences in PAR between treatments in the morning (8-10am) ($p = 0.7095$) or at midday (11am-1pm) ($p = 0.1196$). Shown in figure 36, morning and midday PAR measurements were averaged, resulting in average daily PAR of 1308 µmols/m^2/sec in the control and 1168 µmols/m^2/sec in the thin plus burn treatment. Although differences were not significant ($p = 0.2135$), light intensity was greater in the control treatment, which was unexpected due greater tree densities in the control treatment. This result may indicate that *L. dalmatica* plants may be shade intolerant, and in areas where tree density is high (e.g. the control treatment in this study), this noxious weed occupied the sunniest sites. Because *L. dalmatica* can prolifically invade disturbed sites and sprout after fire (Whitson et al. 1992), and as this study shows, appears to prefer high light intensity sites, strict monitoring of this noxious weed must co-occur with restoration practices that include thinning and burning disturbances.

As expected, forest floor depths were lower in the thinned plus burned treatment than the control. Litter layer depth on *L. dalmatica* plots, shown in table 7 and figure 37, was significantly greater in the control (0.7867 in) than the thin plus burn treatment (0.1897 in) ($p < 0.0001$). Fermentation plus humus layer was significantly greater in the control (1.4067 in) than the thin plus burn treatment (0.6539 in) ($p < 0.0001$).

Light intensity was different between the treatments on *L. argenteus* and *B. tricholepis* plots, showing that these two native plants may be better able to occupy sites of differing light availability and forest floor depths than *L. dalmatica* plants, which seem to be more site specific requiring high light intensity. Litter depths associated with *L. argenteus* plots were greater than litter depths on *B. tricholepis* and *L. dalmatica* plots. However, fermentation plus humus depths associated with *L. dalmatica* plots were greater than on *L. argenteus* and *B. tricholepis* plots. Lower forest floor depths on *B. tricholepis* plots may be due to a possible preference for open canopies by the native bunchgrass.

Table 7. *Linaria dalmatica* ANOVA summary comparing PAR and forest floor depths in the control, partial and full treatments at FUWI in 2001. Measurements were collected on 1m^2 plots. Different lower case letters after treatment values indicate that means are significantly different. $\alpha = 0.05$, $n = 30$ (control) and 39 (thin plus burn).

Linaria dalmatica	**Year**	**Control**	**Thin+Burn**	**p-value**
PAR 8-10am (µmols/m^2/sec)	2001	957.60a	909.079a	0.7095
PAR 11am-1pm (µmols/m^2/sec)	2001	1657.53a	1420.49a	0.1196
Avg Daily PAR (µmols/m^2/sec)	2001	1307.57a	1168.10a	0.2135
Litter depth (in)	2001	**0.7867a**	**0.1897b**	<0.0001
Fermentation + Humus (in)	2001	**1.4067a**	**0.6539b**	<0.0001

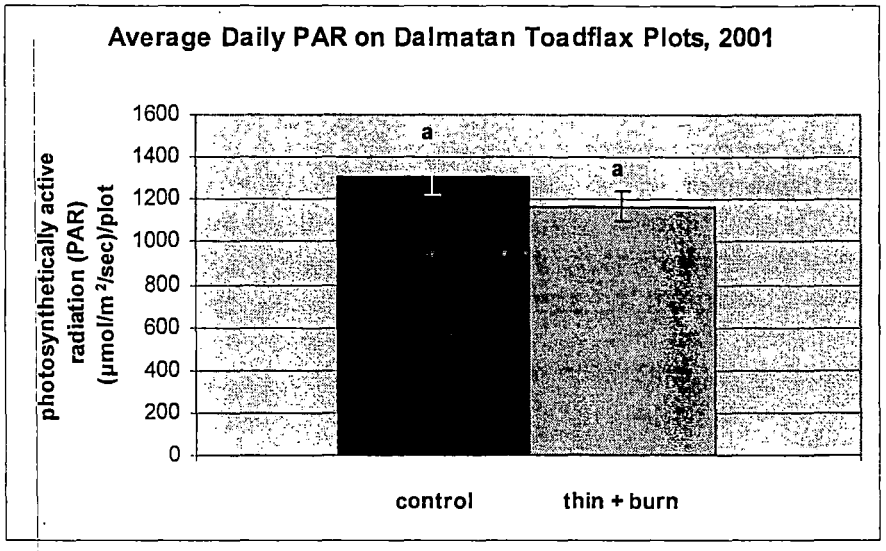


Figure 36. Average daily light intensity (PAR at 8-10am and 11am-1pm) comparison on *Linaria dalmatica* plots using ANOVA in control (n = 30) and thin + burn treatments (n = 39) at FUWI. α = 0.05. Different lower case letters above standard error bars indicate that mea are significantly different.

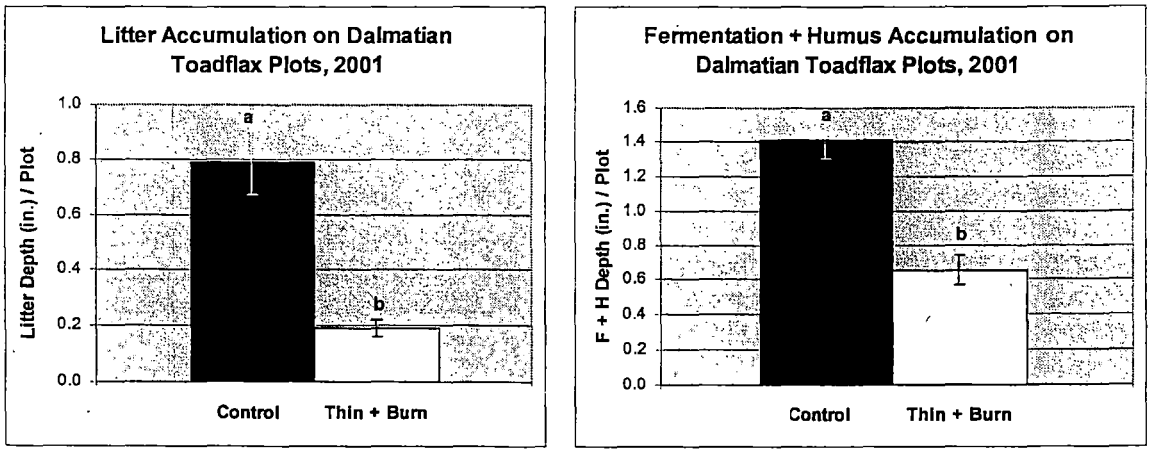


Figure 37. Litter accumulation and fermentation + humus accumulation comparison on *Linaria dalmatica* plots using ANOVA in control (n = 30) and thin + burn treatments (n = 39) at FUWI. α = 0.05. Different lower case letters above standard error bars indicate that mear are significantly different. α = 0.05.

RELATIONSHIPS

Relationships between growth and reproduction variables and the environmental variables light intensity and forest floor depths are shown in tables 8-13 for each of the three species, *Lupinus argenteus*, *Blepharoneuron tricholepis*, and *Linaria dalmatica*. An in-depth discussion regarding these relationships for *L. argenteus* and *B. tricholepis* can be found in Machina (2003).

Lupinus argenteus

Table 8 shows r^2-values and p-values from simple linear regression analyses between *Lupinus argenteus* plant variables and environmental variables measured on *L. argenteus* $1m^2$ plots. When considering all plots in all three treatments (n = 152), the overall relationship of plant growth and reproductive variables as a function of average daily light intensity (PAR) was slightly positive, but weak, and no relationship was detected as a function of forest floor depths. Average daily PAR had a slight positive effect on height ($r^2 = 0.06$, $p = 0.0017$), cover ($r^2 = 0.07$, $p = 0.0011$), biomass ($r^2 = 0.15$, $p = 0.0006$), and number of reproductive stalks ($r^2 = 0.07$, $p = 0.0010$). Average daily PAR had no effect on plant density ($r^2 = 0.0003$, $p = 0.8329$). Morning, midday, and afternoon PAR were also examined using simple linear regressions using growth and reproduction variables. Morning and midday PAR had a more pronounced effect on *L. argenteus* growth and reproduction variables than afternoon PAR, but average daily PAR had the most pronounced effect on growth and reproduction. Forest floor variables did not have a cause and effect relationship with growth or reproductive variables, shown in table 8.

Because the relationships between environmental variables and growth and reproduction variables for *L. argenteus* were weak, relationships were more closely examined by stratifying data into overstory canopy (or patch) types. These overstory canopy types are described in the methods section and encompass presettlement, postsettlement retained, postsettlement removed, and grass. Results are shown in table 9.

Regression relationships between light intensity variables and plant growth and reproduction variables were strongest under the postsettlement retained tree canopy cover type. The postsettlement canopy type occurs in all three treatments, however, there are fewer postsettlement trees in the restored treatments because of thinning. In the control, where no thinning occurred, trees associated with this canopy type are more densely situated. Under the postsettlement retained canopy type, 22 percent of the variation in *L. argenteus* aerial cover was explained by average daily PAR ($p = 0.0028$) and morning PAR ($p = 0.0022$). Fifty-seven, 20, and 46 percent of the variation in *L. argenteus* biomass was explained by average daily PAR ($p < 0.0001$), morning PAR ($p = 0.0490$), and afternoon PAR ($p = 0.001$), respectively, under the postsettlement retained canopy type. Average daily PAR ($p = 0.0049$) and morning PAR ($p = 0.0006$) each explained 19 and 27 percent, respectively, of the variation in the number of reproductive stalks per *L. argenteus* plant under the postsettlement canopy type.

Table 8. *Lupinus argenteus* growth (height, cover, aboveground biomass, and plot density) and reproduction (# reproductive stalks) simple linear regressions as a function of light intensity (average daily, morning, midday, and afternoon PAR) and forest floor depth (l + f + h, litter, and fermentation + humus depths). R^2-value and p-value are shown. Bolded r^2-values indicate statistical significance. Negative signs before r^2-values indicate negative relationships. $\alpha = 0.05$, n = 152 plants.

Lupinus argenteus	Avg Daily PAR (umols/m²/sec)	8-10am PAR (umols/m²/sec)	11am-1pm PAR (umols/m²/sec)	3-5pm PAR (umols/m²/sec)	L + F + H (in)	Litter (in)	Fermentation + Humus (in)
Height (cm)	**0.06**, p = 0.0017	0.0001, p = 0.8818	**0.06**, p = 0.0021	0.02, p = 0.0714	0.002, p = 0.5606	0.0004, p = 0.8143	0.01, p = 0.2432
Aerial Cover (cm)	**0.07**, p = 0.0011	**0.03**, p = 0.0359	**0.04**, p = 0.0191	0.004, p = 0.4461	0.004, p = 0.4554	0.002, p = 0.5744	0.01, p = 0.3595
Biomass (g), 72 plants	**0.15**, p = 0.0006	**0.09**, p = 0.0110	**0.07**, p = 0.0284	0.02, p = 0.2673	0.03, p = 0.1685	0.02, p = 0.2225	0.02, p = 0.1871
Density (#/plot)	0.0003, p = 0.8329	**0.05**, p = 0.0059	0.02, p = 0.0675	0.003, p = 0.5197	0.02, p = 0.0823	0.01, p = 0.1427	0.02, p = 0.0757
# Reprod Stalks	**0.07**, p = 0.0010	**0.08**, p = 0.0117	0.03, p = 0.0675	0.0007, p = 0.7462	0.005, p = 0.4029	0.003, p = 0.5365	0.01, p = 0.2930

Table 9. *Lupinus argenteus* growth and reproduction simple linear regressions as a function of light intensity and forest floor depth under different tree canopy cover types. R^2-value and p-value are shown. Bolded r^2-values indicate statistical significance. Negative signs before r^2-values indicate negative relationships. $\alpha = 0.05$, n = 46 plants under presettlement canopy, n = 40 plants under postsettlement retained canopy, n = 25 plants under postsettlement removed canopy, n = 41 plants under grassy canopy.

Lupinus argenteus	Overstory Canopy Type	Avg Daily PAR (umols/m²/sec)	8-10am PAR (umols/m²/sec)	11am-1pm PAR (umols/m²/sec)	3-5pm PAR (umols/m²/sec)	L + F + H (in)	Litter (in)	Fermentation + Humus (in)
Height (cm)	**Presettlement**	0.03, p = 02458	-0.02, p = 0.3496	0.01, p = 0.4833	**0.09**, p = 0.0422	0.006, p = 0.6237	0.03, p = 2681	-0.02, p = 0.3084
	Post retained	0.05, p = 0.1522	0.05, p = 0.1742	0.02, p = 0.3364	0.002, p = 0.8066	-0.03, p = 0.2878	-0.04, p = 0.2092	-0.002, p = 0.7633
	Post removed	0.01, p = 0.5851	-0.04, p = 0.3684	0.05, p = 0.3033	0.03, p = 0.4263	0.007, p = 0.6828	0.02, p = 0.4510	-0.04, p = 0.3309
	Grass	0.04, p = 0.2243	0.02, p = 0.3429	0.04, p = 0.2308	-0.0001, p = 0.9493	0.04, p = 0.2091	0.03, p = 0.2911	0.04, p = 0.2222
Aerial Cover (cm)	**Presettlement**	0.009, p = 0.5257	-0.02, p = 0.3474	0.0009, p = 0.8390	0.07, p = 0.0749	0.01, p = 0.4386	0.03, p = 0.2532	-0.002, p = 0.7761
	Post retained	**0.22**, p = 0.0028	**0.22**, p = 0.0022	0.05, p = 0.1468	0.02, p = 0.3712	-0.10, p = 0.0501	**-0.12**, p = 0.0288	-0.02, p = 0.3937
	Post removed	0.01, p = 0.5838	0.06, p = 0.221	-0.008, p = 0.6737	-0.11, p = 0.0981	0.006, p = 0.7081	0.02, p = 0.5	-0.03, p = 0.4034
	Grass	0.09, p = 0.0589	0.08, p = 0.0707	0.05, p = 0.1493	0.00002, p = 0.9797	0.03, p = 0.2661	0.02, p = 0.4045	0.04, p = 0.1987
Biomass (g), 12-21 plants	**Presettlement**	0.11, p = 0.1719	0.00000, p = 0.9917	0.06, p = 0.3075	0.10, p = 0.1814	0.14, p = 0.1200	0.14, p = 0.1131	0.04, p = 0.3920
	Post retained	**0.57**, p < 0.0001	**0.20**, p = 0.0490	0.18, p = 0.0628	**0.46**, p = 0.001	**-0.32**, p = 0.0091	**-0.29**, p = 0.0148	**-0.20**, p = 0.0476
	Post removed	0.09, p = 0.3303	0.21, p = 0.1304	-0.23, p = 0.1170	**-0.41**, p = 0.0252	-0.004, p = 0.8438	-0.002, p = 0.8809	-0.004, p = 0.8415
	Grass	0.13, p = 0.1023	0.04, p = 0.3740	0.009, p = 0.6818	0.07, p = 0.2558	0.17, p = 0.0671	0.14, p = 0.0928	0.17, p = 0.0624
Density (#/plot)	**Presettlement**	0.005, p = 0.6467	-0.003, p = 0.7241	0.03, p 0.2487	-0.006, p = 0.6009	0.0004, p = 0.8897	0.02, p = 0.3711	-0.06, p = 0.1147
	Post retained	0.002, p = 0.8102	-0.02, p = 0.3974	0.01, p = 0.4823	0.005, p = 0.6513	-0.07, p = 0.0906	-0.06, p = 0.1434	-0.07, p = 0.0912
	Post removed	-0.002, p = 0.8493	-0.02, p = 0.4606	-0.007, p = 0.6835	0.03, p = 0.3902	-0.003, p = 0.8112	-0.003, p = 0.8093	-0.0006, p = 0.9055
	Grass	-0.09, p = 0.0610	**-0.14**, p = 0.0180	-0.03, p = 0.3059	-0.00003, p =0.9727	-0.0002, p = 0.9235	-0.003, p = 0.7331	0.005, p = 0.6724
# Reprod Stalks	**Presettlement**	0.01, p = 0.4592	-0.03, p = 0.2728	0.0007, p = 0.8579	**0.10**, p = 0.0291	0.004, p = 0.6583	0.01, p = 0.4765	-0.002, p = 0.7670
	Post retained	**0.19**, p = 0.0049	**0.27**, p = 0.0006	0.04, p = 0.2452	0.01, p = 0.5199	-0.06, p = 0.1296	-0.07, p = 0.1016	-0.02, p = 0.4379
	Post removed	0.001, p = 0.8719	0.13, p = 0.0773	-0.001 p = 0.8766	-0.15, p = 0.0535	0.003, p = 0.7827	0.02, p = 0.5579	-0.04, p = 0.3534

Shown in table 9, decreases in afternoon PAR ($p = 0.0252$) explained 41 percent of the variation in *L. argenteus* biomass increases under the postsettlement removed canopy type, which occurs only in the restored treatments. Under the grass canopy type, where there is little or no tree canopy cover, morning PAR ($p = 0.0041$) explained 19 percent of the variation in the number of reproductive stalks per *L. argenteus* plant. The only environmental variable measured that explained any variation in *L. argenteus* indicator plant height was afternoon light intensity ($r^2 = 0.09$, $p = 0.0422$) under the presettlement canopy type.

Forest floor depths had very little impact on *L. argenteus* growth and reproduction when all data were lumped, but when data were separated into canopy types, plants were affected by forest floor depth under the postsettlement retained canopy type (table 9). Decreases in litter depth explained 12 percent of the variation in aerial cover of *L. argenteus* plants under the postsettlement retained canopy type ($p = 0.0288$). Also under this canopy type, decreases in total forest floor ($p = 0.0091$), litter ($p = 0.0148$), and fermentation plus humus ($p = 0.0476$) depths explained 32, 29, and 20 percent, respectively, of the variation in *L. argenteus* biomass.

Blepharoneuron tricholepis

Table 10 shows r^2-values and p-values from simple linear regression analyses between *Blepharoneuron tricholepis* plant variables and environmental variables measured on *B. tricholepis* $1m^2$ plots. When considering all plots in all three treatments ($n = 146$), the overall relationships of plant growth and reproductive variables as a function of average daily light intensity (PAR) is slightly positive, but weak, and as a function of forest floor depths is slightly negative, but weak.

Average daily light intensity (PAR) positively affected height ($r^2 = 0.18$, $p < 0.0001$), cover ($r^2 = 0.21$, $p < 0.0001$), biomass ($r^2 = 0.13$, $p = 0.0018$), and number of reproductive stalks ($r^2 = 0.15$, $p < 0.0001$). Average daily light intensity had a greater effect on growth variables than either morning, midday, or afternoon PAR. Reproduction, however, was most affected by morning PAR ($r^2 = 0.17$, $p < 0.0001$). Sample evidence showed that litter depths negatively affected all *B. tricholepis* growth and reproduction variables ($r^2 = 0.04$-0.13, $p = 0.0001$-0.0191), but that the fermentation + humus forest floor layer was less important to *B. tricholepis* growth and reproduction. Basal cover was very slightly negatively affected by fermentation plus humus depth ($r^2 = 0.03$, $p = 0.0426$).

Because the relationships between environmental variables and growth and reproduction variables for *B. tricholepis* were weak, relationships were more closely examined by stratifying data into overstory canopy types. These overstory canopy types are described in the methods section and encompass presettlement, postsettlement retained, postsettlement removed, and grass. Results are shown in table 11. Regression relationships between light intensity variables and plant growth and reproduction variables were strongest under the grass cover type and the presettlement tree canopy cover type.

Table 10. *Blepharoneuron tricholepis* growth (height, cover, aboveground biomass, and plot density) and reproduction (# reproductive stalks) simple linear regressions as a function of light intensity (average daily, morning, midday, and afternoon PAR) and forest floor depth (l + f + h, litter, and fermentation + humus depths). R^2-value and p-value are shown. Bolded r^2-values indicate statistical significance. Negative signs before r^2-values indicate negative relationships. $\alpha = 0.05$, n = 146 plants.

Blepharoneuron tricholepis	Avg Daily PAR (umols/m^2/sec)	8-10am PAR (umols/m^2/sec)	11am-1pm PAR (umols/m^2/sec)	3-5pm PAR (umols/m^2/sec)	L + F + H (in)	Litter (in)	Fermentation + Humus (in)
Height (cm)	**0.18**, p < 0.0001	**0.06**, p = 0.0027	**0.07**, p = 0.0016	**0.10**, p < 0.0001	**-0.08**, p = 0.0004	**-0.13**, p < 0.0001	-0.03, p = 0.0523
Basal Cover (mm)	**0.21**, p < 0.0001	**0.04**, p = 0.0149	**0.09**, p = 0.0002	**0.14**, p < 0.0001	**-0.08**, p = 0.0005	**-0.12**, p < 0.0001	**-0.03**, p = 0.0426
Biomass (g), 72 plants	**0.13**, p = 0.0018	**0.08**, p = 0.0135	0.03, p = 0.1533	**0.10**, p = 0.0055	-0.01, p = 0.3470	**-0.12**, p = 0.0035	0.001, p = 0.7841
Density (#/plot)	0.001, p = 0.7279	0.004, p = 0.4432	0.001, p = 0.7666	0.001, p = 0.7619	**-0.04**, p = 0.0226	**-0.04**, p = 0.0191	-0.02, p = 0.1248
# Reprod Stalks	**0.15**, p < 0.0001	**0.17**, p < 0.0001	**0.03**, p = 0.0431	**0.05**, p = 0.0099	-0.02, p = 0.0946	**-0.06**, p = 0.0035	-0.002, p = 0.6137

Table 11. *Blepharoneuron tricholepis* growth and reproduction simple linear regressions as a function of light intensity and forest floor depth under different tree canopy cover types. R^2-value and p-value are shown. Bolded r^2-values indicate statistical significance. Negative signs before r^2-values indicate negative relationships. $\alpha = 0.05$, n = 21 plants under presettlement canopy, n = 49 plants under postsettlement retained canopy, n = 31 plants under postsettlement removed canopy (occurs only in partial and full treatments), n = 45 plants under grassy canopy.

Blepharoneuron tricholepis	Overstory Canopy Type	Avg Daily PAR (umols/m^2/sec)	8-10am PAR (umols/m^2/sec)	11am-1pm PAR (umols/m^2/sec)	3-5pm PAR (umols/m^2/sec)	L + F + H (in)	Litter (in)	Fermentation + Humus (in)
Height (cm)	**Presettlement**	0.12, p = 0.1277	**0.32**, p = 0.0073	-0.005, p = 0.7663	0.16, p = 0.0709	-0.03, p = 0.4693	-0.01, p = 0.6301	-0.02, p = 0.5104
	Post retained	0.02, p = 0.3050	0.01, p = 0.4694	0.005, p = 0.6302	0.01, p = 0.4107	**-0.17**, p = 0.0034	**-0.13**, p = 0.0094	**-0.10**, p = 0.0302
	Post removed	0.05, p = 0.2367	-0.005, p = 0.7147	0.07, p = 0.1386	0.07, p = 0.1444	0.10, p = 0.0913	0.02, p = 0.4382	0.08, p = 0.1170
	Grass	**0.39**, p < 0.0001	**0.10**, p = 0.0325	**0.24**, p = 0.0007	**0.18**, p = 0.0040	-0.06, p = 0.1112	**-0.14**, p = 0.0115	0.003, p = 0.7080
Basal Cover (mm)	**Presettlement**	0.17, p = 0.0644	0.11, p = 0.1428	0.02, p = 0.5727	0.15, p = 0.0814	-0.07, p = 0.2601	-0.07, p = 0.2596	-0.04, p = 0.3588
	Post retained	**0.16**, p = 0.0043	0.04, p = 0.1734	0.05, p = 0.1059	**0.11**, p = 0.0177	-0.05, p = 0.1258	**-0.11**, p = 0.0219	-0.01, p = 0.4781
	Post removed	0.12, p = 0.0539	-0.004, p = 0.7400	-0.03, p = 0.3375	**0.19**, p = 0.0156	0.05, p = 0.2196	0.03, p = 0.3247	0.04, p = 0.3120
	Grass	**0.17**, p = 0.0056	0.04, p = 0.1691	**0.12**, p = 0.0209	0.06, p = 0.0983	**-0.11**, p = 0.0273	**-0.10**, p = 0.0322	-0.02, p = 0.3942
Biomass (g), 12-21 plants	**Presettlement**	0.21, p = 0.1105	**0.90**, p < 0.0001	-0.01, p = 0.7163	0.28, p = 0.0604	-0.002, p = 0.8757	-0.01, p = 0.7581	-0.001, p = 0.9318
	Post retained	0.04, p = 0.3266	0.0002, p = 0.9488	0.06, p = 0.2497	0.03, p = 0.4062	-0.03, p = 0.4320	**-0.24**, p = 0.0149	0.004, p = 0.7641
	Post removed	0.04, p = 0.4877	0.05, p = 0.4348	0.01, p = 0.7421	0.001, p = 0.9101	**0.27**, p = 0.0486	**0.26**, p = 0.0537	0.19, p = 0.1023
	Grass	**0.20**, p = 0.0450	0.002, p = 0.8492	0.10, p = 0.1831	**0.24**, p = 0.0294	-0.03, p = 0.4982	-0.18, p = 0.0615	0.005, p = 0.7760
Density (#/plot)	**Presettlement**	-0.02, p = 0.5369	-0.10, p = 0.1698	0.03, p = 0.4715	-0.11, p = 0.1412	-0.12, p = 0.1238	-0.06, p = 0.2773	-0.10, p = 0.1699
	Post retained	-0.0002, p = 0.9182	0.01, p = 0.6163	-0.01, p = 0.4898	0.002, p = 0.7767	**-0.12**, p = 0.0134	-0.05, p = 0.1300	**-0.10**, p = 0.0290
	Post removed	-0.10, p = 0.0816	-0.001, p = 0.9024	-0.03, p = 0.3660	-0.09, p = 0.1082	-0.002, p = 0.8215	-0.03, p = 0.3741	0.000, p = 0.9761
	Grass	-0.001, p = 0.8530	0.01, p = 0.5014	-0.02, p = 0.3172	0.0002, p = 0.9244	-0.02, p = 0.4176	-0.03, p = 0.2601	0.0000, p = 0.9642
# Reprod Stalks	**Presettlement**	0.06, p = 0.2915	**0.67**, p < 0.0001	-0.07, p = 0.2368	0.11, p = 0.1363	0.01, p = 0.6264	0.01, p = 0.6670	0.01, p = 0.6787
	Post retained	0.05, p = 0.1417	0.004, p = 0.6724	0.04, p = 0.1695	0.01, p = 0.4327	**-0.13**, p = 0.0105	**-0.15**, p = 0.0065	-0.06, p = 0.0910
	Post removed	**0.15**, p = 0.0305	**0.15**, p = 0.0296	**0.14**, p = 0.0373	0.0002, p = 0.9354	0.05, p = 0.2318	-0.002, p = 0.7948	0.06, p = 0.1697
	Grass	**0.32**, p < 0.0001	**0.34**, p < 0.0001	**0.09**, p = 0.0442	**0.09**, p = 0.0487	-0.003, p = 0.7418	-0.02, p = 0.3149	0.01, p = 0.5397

In the grass cover type, 39 percent of the variation in *B. tricholepis* height ($p < 0.0001$), 17 percent of the variation in basal cover ($p = 0.0056$), 20 percent of the variation in biomass ($p = 0.0450$), and 32 percent of the variation in number of reproductive stalks ($p < 0.0001$) was explained by average daily PAR. In the grass cover type, afternoon PAR had the greatest effect on *B. tricholepis* biomass ($r^2 = 0.24$, $p = 0.0294$), and morning PAR had the greatest effect on *B. tricholepis* number of reproductive stalks ($r^2 = 0.34$, $p < 0.0001$).

Under the presettlement tree canopy cover type, morning PAR caused 32 percent of the variation in *B. tricholepis* height ($p = 0.0073$). Biomass ($r^2 = 0.90$, $p < 0.0001$) and number of reproductive stalks ($r^2 = 0.67$, $p < 0.0001$) per *B. tricholepis* plant were strongly affected by morning PAR under presettlement trees.

Under the postsettlement retained canopy type, average daily PAR caused 16 percent of the variation in basal cover ($p = 0.0043$). Under the postsettlement removed canopy type, afternoon PAR caused 19 percent of the variation in basal cover ($p = 0.0156$). Number of reproductive stalks per *B. tricholepis* plants was affected by average daily PAR ($r^2 = 0.15$, $p = 0.0305$), morning PAR ($r^2 = 0.15$, $p = 0.0296$), and midday PAR ($r^2 = 0.14$, $p < 0.03737$).

Litter had the greatest effect on *B. tricholepis* plant growth and reproduction. Under the postsettlement retained canopy type, decreases in litter depth caused 13 percent of the variation in *B. tricholepis* height ($p = 0.0094$), 11 percent of the variation in *B. tricholepis* basal cover ($p = 0.0219$), 24 percent of the variation in *B. tricholepis* biomass ($p = 0.0149$), and 15 percent of the variation in *B. tricholepis* number of reproductive stalks ($p = 0.0065$). Another notable forest floor effect is of litter on biomass in the postsettlement removed canopy type ($r^2 = 0.26$, $p < 0.0537$).

Linaria dalmatica

Table 12 shows r^2-values and p-values from simple linear regression analyses between *Linaria dalmatica* plant variables and environmental variables measured on *L. dalmatica* $1m^2$ plots. When considering all plots in both treatments together ($n = 69$), the overall relationships of plant growth and reproductive variables as a function of average daily light intensity (PAR) and forest floor depths were nearly non-existent.

Morning PAR had a slight negative effect on *L. dalmatica* height ($r^2 = 0.06$, $p = 0.0407$). Total forest floor depth had a slight negative effect on *L. dalmatica* density ($r^2 = 0.08$, $p = 0.0165$). Average daily and midday PAR, and litter and fermentation plus humus layers had no effect on *L. dalmatica* growth or reproduction when considering all plots in both treatments together.

Because the relationships between environmental variables and growth and reproduction variables for *L. dalmatica* were weak, relationships were more closely examined by stratifying data into overstory canopy types. These overstory canopy types are described in the methods section and encompass presettlement, postsettlement retained, postsettlement removed, and grass. Results are shown in table 13.

Table 12. *Linaria dalmatica* growth (height, cover, aboveground biomass, and plot density) and reproduction (# reproductive stalks) simple linear regressions as a function of light intensity (average daily, morning, midday, and afternoon PAR) and forest floor depth (l + f + h, litter, and fermentation + humus depths). R^2-value and p-value are shown. Bolded r^2-values indicate statistical significance. Negative signs before r^2-values indicate negative relationships. $\alpha = 0.05$, n = 69 plants.

Linaria dalmatica	Avg Daily PAR (umols/m²/sec)	8-10am PAR (umols/m²/sec)	11am-1pm PAR (umols/m²/sec)	L + F + H (in)	Litter (in)	Fermentation + Humus (in)
Height (cm)	-0.004, p = 0.5958	**-0.06**, p = 0.0407	0.01, p = 0.2824	-0.0004, p = 0.8694	0.002, p < 0.7484	-0.004, p = 0.6291
Aerial Cover (cm)	0.00, p = 0.9741	-0.01, p = 0.3249	0.009, p = 0.4270	-0.002, p = 0.7031	-0.01, p = 0.3825	0.0005, p = 0.8508
Biomass (g), 72 plants	0.03, p = 0.3971	0.002, p = 0.8212	0.03, p = 0.3679	-0.004, p = 0.7414	-0.03, p = 0.3386	0.02, p = 0.5190
Density (#/plot)	0.008, p = 0.4696	-0.0002, p = 0.8998	0.02, p = 0.2647	**-0.08**, p = 0.0165	-0.05, p = 0.0672	-0.04, p = 0.0820
# Reprod Stalks	0.004, p = 0.5894	-0.003, p = 0.6745	0.02, p = 0.2998	0.02, p = 0.2207	0.04, p = 0.0814	0.001, p = 0.7965

Table 13. *Linaria dalmatica* growth and reproduction simple linear regressions as a function of light intensity and forest floor depth under different tree canopy cover types. R^2-value and p-value are shown. Bolded r^2-values indicate statistical significance. Negative signs before r^2-values indicate negative relationships. $\alpha = 0.05$, n = 18 plants under presettlement canopy, n = 15 plants under postsettlement retained canopy, n = 12 plants under postsettlement removed canopy, n = 23 plants under grassy canopy.

Linaria dalmatica	Overstory Canopy Type	Avg Daily PAR (umols/m²/sec)	8-10am PAR (umols/m²/sec)	11am-1pm PAR (umols/m²/sec)	L + F + H (in)	Litter (in)	Fermentation + Humus (in)
Height (cm)	**Presettlement**	-0.01, p = 0.6390	-0.001, p = 0.8840	-0.02, p = 0.6244	-0.01, p = 0.6772	**0.22**, p = 0.0482	-0.10, p = 0.1974
	Post retained	0.02, p = 0.6220	-0.19, p = 0.1093	0.05, p = 0.4019	0.03, p = 0.5126	0.04, p = 0.4834	0.007, p = 0.7511
	Post removed	**0.43**, p = 0.0210	0.03, p = 0.6220	0.25, p = 0.0991	**0.36**, p = 0.0376	0.04, p = 0.5336	0.30, p = 0.0665
	Grass	-0.02, p = 0.5256	-0.10, p = 0.1455	0.01, p = 0.6043	-0.10, p = 0.1318	-0.002, p = 0.8500	**-0.20**, p = 0.0346
Aerial Cover (cm)	**Presettlement**	-0.0002, p = 0.9549	0.02, p = 0.6218	-0.02, p = 0.6056	-0.02, p = 0.5463	0.04, p = 0.4054	-0.07, p = 0.2810
	Post retained	0.05, p = 0.4110	0.004, p = 0.8332	0.03, p = 0.5009	-0.01, p = 0.6521	-0.01, p = 0.6594	-0.005 p = 0.8018
	Post removed	0.04, p = 0.5272	0.007, p = 0.8019	0.02, p = 0.7009	0.26, p = 0.0911	-0.08, p = 0.3882	0.32, p = 0.0547
	Grass	0.002, p = 0.8361	-0.03, p = 0.4128	0.06, p = 0.2668	-0.02, p = 0.5130	0.007, p = 0.6971	-0.10, p = 0.1404
Biomass (g), 4-9 plants	**Presettlement**	-0.0002, p = 0.9761	-0.003, p = 0.9028	0.001, p = 0.9425	0.14, p = 0.3684	**0.86**, p = 0.0009	-0.002, p = 0.9092
	Post retained	-0.00005, p = 0.9875	0.35, p = 0.1604	-0.19, p = 0.2755	-0.30, p = 0.1562	-0.39, p = 0.0968	0.002, p = 0.9083
	Post removed	0.64, p = 0.1988	0.04, p = 0.7917	0.25, p = 0.4977	0.57, p = 0.2468	0.000, p = —	0.57, p = 0.2468
	Grass	0.10, p = 0.4077	0.008, p = 0.8226	0.13, p = 0.3345	0.39, p = 0.0744	**0.48**, p = 0.0382	0.002, p = 0.9059
Density (#/plot)	**Presettlement**	0.05, p = 0.3794	0.08, p = 0.2697	0.002, p 0.8569	-0.20, p = 0.0644	-0.04, p = 0.4324	-0.21, p = 0.0568
	Post retained	-0.06, p = 0.3933	-0.006, p = 0.7861	-0.003, p = 0.8417	-0.06, p = 0.9504	-0.21, p = 0.0765	0.0004, p = 0.9404
	Post removed	0.12, p = 0.2637	0.02, p = 0.6925	0.05, p = 0.4788	**0.35**, p = 0.0435	-0.001, p = 0.9110	**0.35**, p = 0.0440
	Grass	-0.0008, p = 0.8987	-0.04, p = 0.3477	0.03, p = 0.4561	-0.06, p = 0.2431	0.0008, p = 0.8998	**-0.17**, p = 0.0481
# Reprod Stalks	**Presettlement**	-0.003, p = 0.8189	-0.14, p = 0.1279	0.07, p = 0.3045	0.06, p = 0.3312	**0.25** p = 0.0360	0.008, p = 0.7175
	Post retained	-0.006, p = 0.7891	-0.25, p = 0.0550	0.03, p = 0.4933	0.03, p = 0.5045	0.06, p = 0.3568	0.002 p = 0.8659
	Post removed	-0.007, p = 0.7990	-0.006, p = 0.8038	-0.00003 p = 0.9870	-0.02, p = 0.6546	-0.01, p = 0.7158	-0.01, p = 0.7254
	Grass	0.05, p = 0.3125	0.05, p = 0.3222	0.009, p = 0.6644	0.02, p = 0.5089	0.03, p = 0.4659	0.00003, p = 0.9805

L. dalmatica height under the postsettlement removed canopy type was the only variable significantly affected by light. Forty-three percent of the variation in height was caused by average daily PAR ($p = 0.0210$) under the postsettlement removed canopy type. Under the presettlement tree canopy type, litter had a positive effect on *L. dalmatica* height ($r^2 = 0.22$, $p = 0.0482$), biomass ($r^2 = 0.86$, $p = 0.0009$), and number of reproductive stalks ($r^2 = 0.25$, $p = 0.0360$). There were no significant effects of forest floor depths under the postsettlement retained canopy type. Under the postsettlement removed canopy type, *L. dalmatica* height was positively affected by total forest floor depth ($r^2 = 0.36$, $p = 0.0376$), and *L. dalmatica* density was positively affected fermentation plus humus ($r^2 = 0.35$, $p = 0.0440$). Finally, in the grass cover type, fermentation plus humus negatively affected *L. dalmatica* height ($r^2 = 0.20$, $p = 0.0346$) and density ($r^2 = 0.17$, $p = 0.0481$), and litter positively affected *L. dalmatica* biomass ($r^2 = 0.48$, $p = 0.0382$).

There was no difference in PAR between treatments on *L dalmatica* plots (table 7, figure 36). Therefore, the negligible effect of light intensity on *L. dalmatica* plant growth and reproduction was expected. Forest floor depth affected *L. dalmatica* growth or reproduction under all cover types except the postsettlement retained cover type. Significant relationships between *L. dalmatica* growth or reproduction and forest floor depth were both positive and negative, indicating an ability of *L. dalmatica* to survive successfully with either shallow or deep forest floor depths.

CHAPTER 4

RESULTS AND DISCUSSION OF OBJECTIVES 2 AND 3:

Seed Collection and Seed Germination of Two Native Plants and Two Non-Native Noxious Weeds in Northern Arizona Ponderosa Pine Forests

Objective 2. To collect seeds from these four species for germination trials, and to add to the body of knowledge on plant seed collection in northern Arizona. Please note that as of 2000 cheatgrass was removed from this study.

Objective 3. To conduct germination tests on these four species to determine germination percentages and mean germination time under varied temperatures an substrates.

SEED COLLECTION AND STORAGE

In northern Arizona, seeds are most successfully sown between mid June ar mid July, just prior to or during monsoon rains (Lavin and Springfield 1955). *Lupinu argenteus* seed matures from September through November, and seed is easily los to predation. Seed drops as soon as pods ripen and split open, which makes collection of viable seed time-sensitive. Many seeds collected in the green doughy pod stage (see Table 1, phenophase 9) just before maturation, as recommended b the USDA (1961), did not tend to mature in collection bags. In addition, a high rate c insect infestation (possibly a weevil) occurred inside collection bags on seeds collected in the green doughy pod stage. We found that the best method of seed collection for *L. argenteus* is to fasten nylon netting around plants with string when plants are in the green doughy pod phenophase. When pods dry out and dehisce, ripe lupine seeds are released into the net and can be collected up to several week later. Without the use of nets, ripe seeds are difficult to capture before being releas to the ground where seeds are vulnerable to fungus, moisture, and predation. Durin the 2001 growing season, it was common to observe an *L. argenteus* plant in all six reproductive phenophases at once. An *L. argenteus* plant may bear different seeds at one time that are developing, ripening, or dehiscing. Ripe lupine seeds remain or the plant for just a few days before pods dehisce and seeds release (author's personal observation), so it is important to rely on seed capture to increase yields and limit seed collection time.

Ripe *L. argenteus* seeds are a rich purplish-brown and can have mottled coloring. Seeds are round in shape and about 4 mm long, 3 mm wide, and 3 mm thick (author's personal observation). The seed set period is quite long, allowing for good reproductive strategy. During the 1999, 2000, and 2001 growing seasons, *L. argenteus* set ripe seed between mid July and late October. The longest period plants produced ripe seeds was in 2001 in the control treatment for three and one-half months. The shortest period plants produced seed was in 2000 during a droug

in the full treatment for one month. In the same drought year, control plants did not set any ripe seed (Machina, unpublished data).

L. argenteus plants are difficult to successfully transplant from the wild (author's personal experience). Taproots are stout and deep, and when plants are dug up, the shallowly excavated taproot is usually too short to support successful transplanting. Plants transplanted from the wild, died within one month (L. Machina personal observation). Transplanting experiments are needed to confirm this observation.

Seed collection of *Blepharoneuron tricholepis* is straight forward. Seeds must first be examined to ensure they are hard and black, and not white, soft, and immature or not already dehisced. A hand lens may be required for checking ripeness. Running hands over inflorescences while pulling in an upwards motion results in a handful of seed, glumes, paleas and other plant debris. Seeds must be separated using a seed blower or by hand. However, if using seeds later in a broadcast seeding, the extraneous grass debris along with the seeds would probably not be problematic in successful germination.

Ripe *B. tricholepis* seeds are tiny, approximately 3 mm long and 1 mm wide, and have a brownish-black smoky quartz color (author's personal observation). Seeds are susceptible to a fungal infestation that may be a rust, which causes seeds to turn bright orange, and likely nonviable, and causes small black spots on the leaves. The window of seed maturity is about 1 month in October and November compared with three months for *L. argenteus*. The hard (ripe) seed period is short, but uniform within populations. When one *B. tricholepis* plant is in the hard seed phenophase, most likely, all other reproductive *B. tricholepis* plants in the extended vicinity are in the same phenophase. During the 1999, 2000, and 2001 growing seasons, *B. tricholepis* set ripe seed between early October and mid-November. The longest period plants produced ripe seeds was in 2001 in all three treatments for one month. The shortest period plants produced seed was for two weeks during the 2000 drought in all three treatments.

Cleaning and sorting *B. tricholepis* seed may require a hand lens and tweezers due to the small seed size and large amount of plant debris collected along with seed. Efficiency of pine dropseed seed processing would be greatly enhanced through the use of a seed blower.

B. tricholepis can be transplanted successfully (author's personal experience). Medium to large-sized *B. tricholepis* bunchgrasses are easily dug and replanted. Plants should be transplanted at the onset of summer monsoon rains to avoid unnecessary manual watering (author's personal observation). Additional transplanting experiments are necessary to confirm this observation.

Seed of *L. argenteus* and *B. tricholepis* should be stored dry, in breathable paper bags, at room temperature. Flagstaff's climate is dry enough that moisture is not an issue. When placed in a refrigerated cold room (temp 5 °C), most *L. argenteus* seeds became moldy (Machina, unpublished data). Greater humidity (up to 99%) in the cold room than at room temperature storage probably attributed to the fungus.

These results demonstrate that there is a longer window of opportunity to collect *L. argenteus* seeds than *B. tricholepis* seeds, but that both species' phenologies must be observed during any year that a seed collection is desirable in

order to optimize seed collection time and increase yields. Methods for successful seed collection, storage and germination of the legume *L. argenteus* and the grass *B. tricholepis* will provide direction for understory restoration management of these two species in northern Arizona ponderosa pine forests.

Linaria dalmatica seed matures as early as mid July through mid November in northern Arizona. Capsules containing seed from the previous year can be collected all year, although it is are uncertain if old seeds are viable. Seeds do, however, appear to be quite hardy. Larger individuals of *L. dalmatica* may produce up to a half million seeds per year (Saner et al. 1994). Gloves are helpful in stripping the sharply pointed capsules from the plants. Extreme care should be taken when collecting, handling, and transporting the tiny seeds of the invasive forb so that unintended spread does not occur. Cleaning and sorting can be difficult due to the small seed size and large amount of plant debris collected. Unused seeds should be placed in a paper bag and heated on high heat in a microwave oven for 3-5 minutes to ensure non-viability before discarding (Willey 2000). Efficiency of *L. dalmatica* seed processing would be greatly enhanced through the use of a seed blower.

Bromus tectorum seed is prolific and easily collected. The annual plant often reproduces twice per growing season, once in the late spring/early summer, then again in the fall. Gloves are helpful when stripping the awned seeds from the plant. Ripe seeds easily attach to animal fur and clothing materials, allowing transport of this noxious weed. Extreme care should be taken when collecting, handling, and transporting *B. tectorum* seed so unintended spread does not occur. The large amount of plant debris surrounding *B. tectorum* seed makes cleaning and sorting difficult. Efficiency of cheatgrass seed processing would be greatly enhanced through the use of a seed blower.

SEED GERMINATION

Table 14 shows germination rates of *Lupinus argenteus*, *Blepharoneuron tricholepis*, *Linaria dalmatica*, and *Bromus tectorum*. Seeds were collected in 1999 and sent to the Arizona State Seed Testing Lab in Phoenix, Arizona in 2000 for germination testing.

B. tricholepis had the greatest germination rate of 88 percent of all four species. *B. tectorum* had a germination rate of 70 percent, *L. argenteus* had a germination rate of 56 percent, and *L. dalmatica* had a germination rate of 43 percent. *L. argenteus* percentage of viable seed was 94%, the greatest of all four species. *L. argenteus* seeds were hand-chosen for seed germination, and because seed size is large and viable seeds are often fat and dark in color, we were more likely to choose viable seed. Although 94 percent of L. argenteus seed were viable, 38 percent were considered hard seed and possibly required scarification for germination, and therefore, did not germinate in this test.

Fifty-seven percent of *Linaria dalmatica* seeds, the greatest of all four species were dead. This is probably due to the tiny size and irregular shape of seeds. Non-viable seeds were essentially undetectable, at least without a hand lens or microscope. Twenty-nine percent of *Bromus tectorum* seeds were dead. *B. tectorum*

seeds were sent within the glumes, therefore, non-viable seed was impossible to detect because glumes covered the seed. Some *L. dalmatica* and *B. tricholepis* seeds collected were from the previous growing season's capsules or plants, which may have contributed to the higher percentages of dead seed. Only 11 percent of *B. tricholepis* seeds were dead. We took *B. tricholepis* seeds out of the glumes and lemmas so that we could determine whether the tiny seeds were viable or there at all. Orange-colored seeds indicated non-viability, while smoky-colored, hard seeds indicated viability.

Table 14. Seed germination results performed by the Arizona State Seed Testing Lab on seeds collected in 1999 from the Coconino National Forest.

Species	silvery lupine *Lupinus argenteus*	pine dropseed *Blepharoneuron tricholepis*	Dalmatian toadflax *Linaria dalmatica*	Downy brome *Bromus tectorum*
Germination	56%	88%	43%	70%
Hard Seed	38%	0%	0%	0%
Firm Seed	0%	0%	0%	0%
Total Viable	94%	88%	43%	70%
Abnormal	2%	1%	0%	1%
Dead	4%	11%	57%	29%
Number of Seed Tested	400	400	400	400
Date Received	8/03/2000	8/03/2000	8/03/2000	8/03/2000
Germination Start Date	8/15/2000	8/16/2000	8/15/2000	8/15/2000
Germination End Date	8/28/2000	9/07/2000	9/14/2000	9/05/2000
Date Results Sent to NAU	9/7/2000	10/10/2000	9/26/2000	9/7/2000
Comments	Germination seed exam only requested	Germination seed exam only requested	Germination seed exam only requested	Germination seed exam only requested
Lot #	2	1	3	4
SAL #	SD00-00597	SD00-00596	SD00-00598	SD00-00599
Account #	160 NAU	160 NAU	160 NAU	160 NAU

CHAPTER 5

MANAGEMENT IMPLICATIONS

Autecological studies are essential to understanding intricacies of an ecosystem. Few in depth studies on single species response to restoration in southwestern ponderosa pine ecosystems exist. Little is known about *Blepharoneuron tricholepis*, an endemic of the Southwest. *Lupinus argenteus* and *Linaria dalmatica* have been studied in other parts of the western United States, but not extensively in northern Arizona ponderosa pine ecosystems.

L. argenteus, *B. tricholepis*, and *L. dalmatica* phenology, growth and reproduction response to localized environmental conditions caused by restoration activities can assist managers in restoring native ecosystems and better understanding response of co-occurring species. New information gained from this research can be utilized in existing and future restoration projects. Applied restorati management is adaptive and allows for implementation of new practices on existin restoration sites as the most current information becomes available.

This study showed that growth and reproduction of *L. argenteus* and *B. tricholepis* increase with restoration thinning and thinning plus burning. It also showed that *L. dalmatica* growth and reproduction increased with thinning plus burning. These findings support previous research in northern Arizona ponderosa pine ecosystems that show increased herbaceous understory productivity associate with thinning and prescribed fire (Arnold 1950, Cooper 1960, Pearson 1964, White e al. 1991, Covington et al. 1997).

If co-occurring herbaceous species respond similarly to *L. argenteus*, *B. tricholepis*, and *L. dalmatica*, then increased growth and reproduction in the restore treatments may be indicative of plant response in open park-like forests where ponderosa pine encroachment is not a problem. Decreased plant growth and reproduction in the control treatment are indicative of plant response in forests that are dense with small diameter ponderosa pine trees. Smaller, less reproductive plants growing in unnaturally dense forests, then, may be unable to carry low-intensity fire as they did 130 years ago (Arnold 1950). Opening the forest canopy ar disturbing the forest floor through restoration thinning can increase plant size and reproduction, as shown in this study with two natives and one noxious weed. Such a prescription also remedies catastrophic forest fires and resulting larger plants may assist in carrying natural, low-intensity fire that often follows restoration thinning. Larger plants with more reproductive stalks allow for greater probability of reproductive success and plant survival, and may be better fuel for prescribed burns in restoration, as well as for naturally-occurring, low-intensity fires. Such fires are pa of a self-sustaining forest ecosystem, which is a goal of many restoration treatments

NOXIOUS WEEDS

Restorationists must acknowledge the potential hazard for noxious weed growth and reproduction to increase simultaneously with native plant growth and reproduction. *Linaria dalmatica* (Dalmatian toadflax), a listed noxious weed in the Scrophulariaceae family, responds similarly to *L. argenteus* and *B. tricholepis* in restoration treatments at the Flagstaff Urban-Wildland Interface (Machina, unpublished data). If noxious weed invasion becomes prevalent in restored ponderosa pine forests, strategies to prevent or minimize impacts must be further researched and implemented.

Although potentially cost-prohibitive at a coarse scale, remediation strategies, such as seeding with natives or mechanical weed removal, would: 1) maintain healthy forest environments, 2) increase support of restoration treatments from those skeptical specifically about the spread of noxious weeds, and 3) protect native vegetation from being outcompeted by noxious weeds.

MANAGEMENT IMPLICATIONS AND FUTURE RESEARCH RECOMMENDATIONS

Ecosystem restoration management and research in southwestern forested ecosystems is of increasing interest to the public due to the imminent danger of catastrophic wildfire. Restorationists' aim to achieve the goal of reducing catastrophic wildfire in combination with restoring more nearly natural conditions that are characteristic of the evolutionary environment of an ecosystem (Society for Ecological Restoration, 1993). In contiguous ponderosa pine forests of the southwestern United States, the vegetative diversity resides in the herbaceous and shrub understory. Managing for diversity and increased production and reproductive capability of native plants in conjunction with restoration thinning and prescribed burning is key to managing these ecosystems.

Successful native understory restoration in southwestern ponderosa pine ecosystems requires progressive approaches that will maintain integrity of understory diversity. Considerations for management and future research follow:

1. Widespread availability of native, local genotype seed and plant materials is necessary
    a. Wild seed collection
    b. Native grass and forb "seed farms" should be created on previously disturbed sites where selected native species can be propagated and seed can be collected year after year
    c. Greenhouse propagation of native plants that have low germination rates in field seeding
    d. Soil seedbank sample collection at restoration sites in order to "grow out" plants in the greenhouse for future transplant at the original restoration site

2. Successful seeding and transplanting techniques for selected native plants must be determined
3. Aggressive management of noxious weeds through seeding of natives mechanical removal, or, as a last resort, chemical treatments
4. Success criteria must be established, and then monitored

CONCLUSION

Findings of increased growth and reproduction of *Lupinus argenteus*, *Blepharoneuron tricholepis*, and *Linaria dalmatica* associated with thinning alone and/or thinning plus burning may assist restorationists in managing for increased production and reproductive success of these two species. Phenological, seed collection, seed storage, and seed germination findings from this research may be useful to managers in restoring ponderosa pine forests of the southwestern United States. In addition, findings from this research may provide insight towards successful management of other, co-occurring understory species, especially those that are early colonizers and/or persistent in established understory communities.

CHAPTER 6

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